No. 1 1936

THE JOURNAL

OF THE

IRON AND STEEL INSTITUTE

VOL. CXXXIII.

EDITED BY

K. HEADLAM-MORLEY

SECRETARY

1936 no. 1
R669.106 I71 v.133

59072 15

PUBLISHED AT THE OFFICES OF THE INSTITUTE
28 VICTORIA STREET, LONDON, S.W.1
1936

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PREFACE.

THE present volume contains thirteen papers presented at the Annual Meeting held in London on May 7 and 8, 1936, together with the discussions and correspondence on them. The following four Special Reports were also published at the time of the Meeting :

Special Report No. 9A.—Discussion, Correspondence, and Reply on "Sixth Report on the Heterogeneity of Steel Ingots."

Special Report No. 10A.—Discussion, Correspondence, and Reply on "Waste-Heat Boilers in Open-Hearth Practice."

Special Report No. 11.—"The Work of the Corrosion Committee," by Dr. W. H. Hatfield, F.R.S.

Special Report No. 12.—"The Work of the Heterogeneity of Steel Ingots Committee," by Dr. W. H. Hatfield, F.R.S.

At the end of Section I. will be found an account of the speeches made at the Annual Dinner.

Section II. is devoted to a survey of the literature on the manufacture and properties of iron and steel, and kindred subjects, and consists of a collection of abstracts of articles from the Transactions and Proceedings of scientific societies and from the technical press. This Section also contains reviews of recent books and bibliographies of literature dealing with the manufacture and properties of iron and steel. The matter included in this Section has already appeared in the Bulletin of the Iron and Steel Institute which is issued monthly.

In front of the title page is inserted a list of the British Standardised Steel Samples, issued jointly by the Iron and Steel Institute and the National Physical Laboratory, showing where and on what terms the samples are available. Proposal forms for Membership and Associateship of the Institute will also be found in the same place.

28, VICTORIA STREET,
LONDON, S.W.1.
September, 1936.

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Abbreviations used in the Text.

Å.	Ångström unit(s).
A.C.	air-cooled; alternating current.
A.H.	air-hardened.
amp.	ampère(s).
amp.hr.	ampère-hour(s).
atm.	atmosphere(s) (pressure).
Bé.	Baumé (scale).
b.h.p.	brake horse-power.
B.o.T.	Board of Trade.
B.Th.U.	British thermal unit(s).
C.	centigrade (scale).
cal.	calory; calories.
c.c.	cubic centimetre(s).
c.d.	current density.
c.g.s.	centimetre-gramme-second unit(s).
cm.	centimetre(s).
coeff.	coefficient.
const.	constant(s).
c.p.	candle-power.
cu.	cubic.
cwt.	hundredweight(s).
D.C.	direct current.
dia.	diameter(s).
dm.	decimetre(s).
e.m.f.	electromotive force.
F.	Fahrenheit (scale).
ft.	foot; feet.
ft.lb.	foot-pound(s).
gal.	gallon(s).
g.	gramme(s).
H.-F.	high-frequency.
h.p.	horse-power.
h.p.hr.	horse-power-hour(s).
hr.	hour(s).
in.	inch; inches.
in.lb.	inch-pound(s).
K.	absolute temperature (Kelvin scale).
kg.	kilogramme(s).
kg.cal.	kilogramme-calory; -calories.
kg.m.	kilogramme-metre(s).
km.	kilometre(s).
kVA.	kilovolt-ampère(s).
kW.	kilowatt(s).
kWh.	kilowatt-hour(s).
lb.	pound(s).
L.F.	low-frequency.
m.	metre(s).
m.amp.	milliampère(s).
mV.	millivolt(s).
max.	maximum.
mg.	milligramme(s).
min.	minimum; minute(s).
ml.	millilitre(s).
mm.	millimetre(s).
m.m.f.	magnetomotive force.
N.	normal (solution).
N.T.P.	normal temperature and pressure.
O.H.	open-hearth; oil-hardened.
O.Q.	oil-quenched.
oz.	ounce(s).
p.d.	potential difference.
*p*H	hydrogen-ion concentration.
r.p.m.	revolutions per minute.
sec.	second(s).
sp. gr.	specific gravity.
sq.	square.
T.	tempered.
temp.	temperature.
V.	volt(s).
VA.	volt-ampère(s).
Wh.	watt-hour(s).
W.Q.	water-quenched.
yd.	yard(s).
°	degree(s).

SECTION I.

MINUTES OF PROCEEDINGS

AND PAPERS OF

THE IRON AND STEEL INSTITUTE.

ANNUAL MEETING

1936

Editorial assistance has been given by A. E. Chattin, B.Sc. (Hons. Met.), A.I.C., Assistant Secretary, in the preparation of this Section.

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MINUTES OF PROCEEDINGS

AND

PAPERS AND DISCUSSIONS

AT THE

ANNUAL MEETING, 1936.

THE SIXTY-SEVENTH ANNUAL MEETING OF THE IRON AND STEEL INSTITUTE was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday and Friday, May 7 and 8, 1936. Sir HAROLD CARPENTER, F.R.S. (President), was in the Chair.

H.M. KING GEORGE V.

THE PRESIDENT (Sir HAROLD CARPENTER, F.R.S.), in opening the Meeting, made reference to the death of His Majesty King George V. He recalled the fact that His late Majesty had been an Honorary Member of the Institute from 1905 until 1910, when he came to the throne, and he had then become the Patron of the Institute, a position which he held up to the time of his death. As recently as 1934 His late Majesty had shown his interest in the work of the Institute by accepting the Bessemer Gold Medal. Those who had had the privilege of attending at Buckingham Palace to hand the Medal to him would always remember the deep interest which he showed in the Institute's work; it was a very memorable occasion for them. It would be fitting if the members stood for a few moments.

The members stood in silence.

THE PRESIDENT, continuing, said that in the Report of Council the Address of condolence sent by the Institute to His Majesty King Edward VIII., and the reply from the Home Secretary, would be found.

THE Minutes of the previous General Meeting held on September 17 and 18, 1935, in Manchester, were taken as read, and confirmed and signed.

PRESENTATION OF THE REPORT OF COUNCIL AND STATEMENT OF ACCOUNTS FOR 1935.

THE PRESIDENT (Sir HAROLD CARPENTER, F.R.S.), in presenting the Report of Council, said that it would be noticed on p. 21 P that His Majesty King Edward VIII. had been graciously pleased to become the Patron of the Iron and Steel Institute. He would like to express his great satisfaction at that decision of His Majesty. (*Applause.*)

Passing to p. 23 P of the Report, it would be noticed that the Institute had lost its last Original Member, Mr. J. Neilson. At the Dinner last year he had commented on the fact that the Institute had one original member, but during the past year Mr. Neilson had died. Another notable death had occurred during the year under review, namely, that of Mr. Percy Carlyle Gilchrist, the co-discoverer with Mr. Thomas of the basic Bessemer process. Mr. Gilchrist had outlived Mr. Thomas by fifty years. For many years he had lived in retirement, owing to ill health, and many people had not realised that he was still alive. By his death the Institute had lost the last member connected with the initiation of cheap steel and the heavy steel industry.

Passing on to p. 30 P, he would like to say a few words about the Symposium on the Welding of Iron and Steel which had been held last year. Two thousand sets of volumes had been prepared, of which to date 1300 had been sold; 100 had been presented, and there remained 600, which were now being disposed of. There was every reason to hope that all the copies would be sold, and he thought he might say that the highest expectations which the Council had had as to the usefulness of the Symposium were being realised.

On p. 31 P of the Report the members would notice a section headed " Relations with other Societies and Technical Institutes." It seemed to the Council that the time had come when the Institute might profitably consider whether it could not do something to increase its own usefulness and that of the other metallurgical societies by a policy of co-operation. The body with which the Institute was most closely connected from the point of view of membership was the Institute of Metals; there were 300 members who were common to both Institutes. It had seemed to the Council that the Institute of Metals might be approached with a view to ascertaining whether there were any ways in which the two Institutes could co-operate usefully with one another. He would like to make it clear that it was not intended that there should be any interference with the independence of either Institute.

Any body with which the Iron and Steel Institute entered into co-operation would preserve its identity and independence. With that reservation, the Council thought that there were many ways which might profitably be pursued in which the Institute and other bodies could support one another and give better service to their members.

Mr. F. W. HARBORD, C.B.E. (Past-President), seconded the motion for the adoption of the Report.

THE HON. TREASURER (Mr. JAMES HENDERSON) then presented the Statement of Accounts. The ordinary income of the General Fund during 1935 had been £8788 16*s.* 9*d.* and the expenditure £10,721 8*s.* 5*d.*, the result being an excess of expenditure over income of £1932 11*s.* 8*d.* The receipts of the Special Appeal Fund during the year, however, had been £2010, and that had been taken into account.

He would like to refer briefly to a few of the items on p. 44 P of the Report. On the income side of the account it would be seen that the first considerable item totalled £5153, being annual subscriptions from members. It would be noticed that practically two-thirds of that sum came from home members and almost one-third from members described as "foreign members." He would prefer to describe the latter as "overseas members"; they were gentlemen resident in the British Colonies and Dominions, in America and on the Continent of Europe. There was present at the meeting a distinguished representative of those members in Dr. Petersen, Director of the Verein deutscher Eisenhüttenleute, whose presence was welcomed by the Institute. The Institute also appreciated the fact that there was an increasing number of applications for membership from gentlemen in Germany.

It would be noticed that an amount of £1300 had been obtained from the sale of the Institute's publications, which showed the very widespread interest taken in the proceedings of the Institute. The sale of those publications was, of course, in addition to the distribution to members by reason of their membership.

The interest on investments had brought in just over £1000, and there was a revenue from the Iron and Steel Industrial Research Council of about £1200 in respect of research. The total of the figures he had mentioned was about £2000 less than the expenditure, which would be seen on the next page. A sum of about £4725 had been spent in salaries, and £1675 on the Library, office rent and expenses. Publishing expenses had amounted to £2075, sundry expenses to about £750, and research to £1500, making a total of £10,721.

It might occur to some members of the Institute that it might be wise, with the lesser income, to cut down the expenditure, but the Council submitted that that would be disastrous. The Institute

must, therefore, look to a continuance of special subscriptions to assist it in its work. The Council did not overlook the fact that membership of the Institute was the best, soundest, and surest source of income, and, with that in mind, he would like to give credit to Mr. Talbot, who was present at the meeting, for a suggestion whereby membership of the Institute was being promoted. Firms and companies giving special subscriptions had been invited to nominate members of their staffs for membership of the Institute, it being understood that the entrance fees and first year's subscriptions of those members would be set against the special subscription. Thereafter, in the second and following years, those members would be responsible for their own subscriptions. Already that scheme had brought the Institute something over one hundred proposals for membership, which were being submitted to the members, with others, at the present meeting. It was hoped that the number of such members would increase as time went on and that the scheme would stimulate interest in the Institute and increase its revenue. He did not think he should leave that subject without referring to the work done by Colonel Sir Charles Wright in initiating the Special Subscription Fund about four years ago. (*Applause.*)

The Symposium had already been referred to by the President, who had touched on the question of the sale of volumes. The account in that connection remained at the moment in suspense. It could hardly be said what the ultimate result would be, but, even if there was a slight deficit, those who had been connected with the publication of the Symposium felt sure that it had been very well worth the money that had been expended upon it.

The Schedule of Investments given in the Report showed that their present market value was well in excess of the figure at which they were taken into account.

THE PRESIDENT expressed the indebtedness of the Institute to Mr. Henderson for the care he took of its finances. To be Treasurer of any scientific or technical society to-day was to occupy a responsible and arduous position which was never free from anxiety. (*Applause.*)

The motion was then put to the meeting and carried.

BALLOT FOR ELECTION OF NEW MEMBERS.

Dr. W. R. MADDOCKS (Sheffield) and Mr. R. A. HACKING (Rotherham) were appointed scrutineers of the ballot for the election of new Members and Associates, and they subsequently announced that the following one-hundred and ninety-three candidates for membership and fifty-six candidates for associateship had been duly elected :

MEMBERS.

AJURIA Y URIGOITIA, SERAFIN .	Victoria, Spain.
ALLEN, WATSON	Rotherham.
ALLMAN, DOUGLAS WILLIAM . .	Rotherham.
ALLOTT, G. W.	Sheffield.
AMOR, LIONEL, M.I.Mech.E. . .	Cardiff.
ARMITAGE, JOSEPH CHARLES STEVENS	Rotherham.
AUST, JOHN, A.M.I.E.E., A.M.E.E. .	Scunthorpe, Lincs.
AUSTIN, PERCY	Rotherham.
AVISON, MAURICE	Mirfield, Yorks.
AYTON, HENRY RICHARD, A.M.I.Mech.E.	London.
BACON, NORWOOD HENRY . .	Sheffield.
BAGNALL, FRANK TAYLOR . .	Sheffield.
BAILLIE, ROBERT WALKER . .	Stockton-on-Tees.
BALFOUR, THE HON. ROBERT ARTHUR	Sheffield.
BALL, G. L.	West Hartlepool.
BARRACLOUGH, SIDNEY . . .	Sheffield.
BARTHOLOMEW, ARNOLD . . .	Rotherham.
BASTIEN, PAUL GASTON, Dr.-ès-Sc. .	Paris, France.
BAXTER, PETER	Glasgow.
BEAUMONT-THOMAS, *Major* LIONEL, M.C., J.P.	London.
BECKETT, MAURICE . . .	Rotherham.
BEECROFT, FRANK	Scunthorpe, Lincs.
BELL, WILLIAM CHARLES . .	Wolverhampton.
BELLAM, GEORGE ALBERT . .	Consett, Co. Durham.
BENNETT, RONALD ORTON, B.A. (Oxon)	Bushey Heath, Herts.
BERGEN, LEWIS S.	New York, N.Y., U.S.A.
BINLEY, JOHN RAE . . .	Coventry.
BIRD, FRANK G.	Tynemouth.
BLACKBOURN, ERNEST . . .	Scunthorpe, Lincs.
BOLHOVITINOV, N. F. . . .	Moscow, U.S.S.R.
BOODLE, JACK NAPOLEON . .	Newcastle, N.S.W., Australia.
BOOTH, ROBERT H. . . .	Workington, Cumberland.
BOWEN, STANLEY OLIVER . .	Stockton-on-Tees.
BRIGGS, ALFRED GEORGE ERNEST .	Sheffield.
BROOKES, JOSEPH TOWNEND . .	Sheffield.
BROUGH, JOB	Rotherham.
BROWN, HECTOR HARPHAM . .	Scunthorpe, Lincs.
BROWN, MALCOLM	Sheffield.
BROWN, WILLIAM	Chesterfield.
BRYDEN, JAMES	Glasgow.
BULLOSS, CECIL BRAMLEY . .	Scunthorpe, Lincs.
BURGESS, CHARLES JOHN . .	Banbury, Oxfordshire.
CARR, JAMES WILLIAM . . .	Rotherham.
CARTWRIGHT, WILLIAM FREDERICK .	Port Talbot, Glam.
CHARLESWORTH, CECIL . . .	Chester.
CHAUDRON, *Professor* GEORGES, Dr.-ès-Sc.	Lille, France.
CHRISTENSEN, CARL D. . . .	Oslo, Norway.
COADE, SAMUEL GORDON . .	Millom, Cumberland.

Cooper, George Wolfenden	Rotherham.
Corbett, Thomas Bryson	Wishaw, Lanarkshire.
Crookes, Frank Victor	Sheffield.
Cutler, Gerard	Sheffield.
Damiron, Paul	Paris, France.
Dann, George Thomas	Stockton-on-Tees.
Davies, Donald Humphrey	Newport, Mon.
Davies, Joseph Leslie Gladstone	Port Talbot, Glam.
Davis, John Vivian Percival	Swansea.
Dawson, Bertrand	Scunthorpe, Lincs.
Deakin, John Bartram	Cardiff.
Dixon, Alfred Francis	Sheffield.
Dobie, William Somerville	Scunthorpe, Lincs.
Douglas, Herbert	Rotherham.
Douglas, Mark	Consett, Co. Durham.
Drummond, David Henry	Middlesbrough.
Dunbar, Alexander	Sheffield.
Duncan, *Sir* Andrew Rae, M.A., LL.D.	London.
Duncanson, John McLean	Glasgow.
Dyson, George Malcolm, B.A. (Oxon), B.Sc., Ph.D.(London), F.I.C., F.C.S.	Loughborough, Leics.
Eastwood, Joseph	Sheffield.
Edwards, Harold, A.I.C.	Chester.
Edwards, Robert	Chester.
Edwards, Thomas William	Rotherham.
Elliott, Harry	Rotherham.
Evans, Cyril	Scunthorpe, Lincs.
Fox, George William	Rotherham.
Franz, Friedrich	Oberhausen (Rhld.), Germany.
Frost, Reginald	Port Talbot, Glam.
Gabe, A. Morgan, B.Sc.	Cardiff.
Gilfillan, George	Sheffield.
Goddard, Arthur Victor	Sheffield.
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Gray, Norman, M.Met.	Cardiff.
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Leeson, Alan Edward	Sheffield.
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Lewis, Gwilym John	Swansea.
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McMullen, James	Workington, Cumberland.
McQuistan, John	Eaglescliffe, Co. Durham.
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Mathieson, Alex Leslie	Consett, Co. Durham.
Millington, Edward	Middlesbrough.
Morgan, Charles Henry	West Hartlepool.
Morgan, Henry Evnydd, M.Sc.	London.
Morgan, Henry Murdock	South Bank, Yorks.
Nekhenzy, *Professor* Julian	Leningrad, U.S.S.R.
Nesbitt, Philip Foster	Sheffield.
Nettmann, *Dr.-Ing.* Paul H. R.	Berlin-Charlottenburg, Germany.
Newbould, Bernard Lee	Worksop.
Nový, Václav	Pilsen, Czechoslovakia.
Ogale, Govind Keshav, M.Sc. (Bombay)	London.
Pannenborg, Johannes	Sterkrade (Rhld.), Germany.
Pears, George William	Medomsley, Co. Durham.
Pickworth, Frederick	Sheffield.
Pollen, Arthur Hungerford, M.A. (Oxon)	London.
Poole, Gordon George Thomas, M.I.Mech.E., A.M.I.E.E.	South Bank, Yorks.
Pope, Ernest Legh	Swansea.
Potter, Rupert Baruadiston, B.A. (Cantab)	Stockport.
Pounder, Aubrey John	Consett, Co. Durham.
Powell, Harry	Rotherham.
Powell, John	Chester.
Prétet, Étienne	Ugine (Savoie), France.
Priestley, Fred Vincent	Middlesbrough.
Pryse, Idris Morgan	Rotherham.
Rasquinet, Albert	Liége, Belgium.
Ratcliff, John Henry Raven	Luton, Beds.
Rawlin, Eric Raymond	Rotherham.
Readman, *Lt.-Col.* Edgar Platt	Solihull, Warwickshire.
Reavell, Brian Noble, B.Sc.	London.

Reid, William	Sheffield.
Reincke, Hans Augustus	Glasgow.
Reusch, *Dr.* Hermann	Oberhausen (Rhld.), Germany.
Rice-Oxley, Francis Bowyer, B.A.	London.
Robinson, Bernard	Rotherham.
Rodgers, John Wentworth, Ph.D.	Sheffield.
Rodgers, William	Buffalo, N.Y., U.S.A.
Rolfe, Robert Thatcher, F.I.C.	Bedford.
Russell, David	Rotherham.
Schnure, Frederick O.	Sparrows Point, Md., U.S.A.
Scott, Charles Henry	Sheffield.
Senior, George	Sheffield.
Short, Cuthbert William	Scunthorpe, Lincs.
Slater, Warrington Finlay	Sheffield.
Snape, Alfred Gorge	Sheffield.
Sohon, Julian A.	Bridgeport, Conn., U.S.A.
Stanfield, Arthur, Assoc.Met.	Sheffield.
Stratford, William Herriott, Assoc.Met.	Sheffield.
Tanner, Gerald Evelyn, B.Sc. (Hons. Met.)	Consett, Co. Durham.
Taylor, John Robinson, B.Sc. (Hons.)	Rotherham.
Thickett, George	Sheffield.
Thomas, Patrick Muirhead, B.A. (Eng.) (Cantab)	Sheffield.
Tomlins, Cyril George	Rotherham.
Tomlinson, Noel Llewelyn	Port Talbot, Glam.
Tupholme, Charles Booth	Sheffield.
Vaughan, Clement	Sheffield.
Village, Rowland	Sheffield.
Walker, Arnold	Scunthorpe, Lincs.
Warnant, *Professor* Edmond	Brussels, Belgium.
Wattsford, Kenneth Comfield Pascow	Blackhill, Co. Durham.
Weinberg, Gregory	Leningrad, U.S.S.R.
Wentrup, *Dr.-Ing.* Hanns	Essen-Ruhr, Germany.
Wheatstone, Henry William	Llanelly, Carm.
White, Harold Clare	Rotherham.
Wilkinson, John Vincent	Rotherham.
Wilkinson, William David John	Port Talbot, Glam.
Williams, Jim	Sheffield.
Willson, Ernest Alfred	London.
Wilson, Douglas	Sheffield.
Wilson, George Eadon	Sheffield.
Woffenden, Tom	Scunthorpe, Lincs.
Wood, Harry Sandiford	West Hartlepool.
Wood, Norman Bland	Rotherham.
Woodman, Joseph, M.Sc.	Sheffield.
Wortley, Glenn	Shotley Bridge, Co. Durham.
Wright, Frederick Victor	Cardiff.
Younghusband, Kenneth	Hawarden, Flintshire.

Associates.

Allsop, Frank Radford	Sheffield.
Ashmore, Eric	Sheffield.
Avery, Howard S.	Mahwah, N.J., U.S.A.
Baker, David Raymond	Cheadle Hulme.
Baker, Robert Cecil	Swinton, nr. Rotherham.
Banks, William	Maryport, Cumberland.
Bell, Oscar Stewart	Scunthorpe, Lincs.
Blick, Charles Richard	Sheffield.
Breeden, Kenneth William	Rotherham.
Brodie, Howard Thomas	Eaglescliffe, Co. Durham.
Broomhead, Frank	Sheffield.
Burnett, Jack	Sheffield.
Campo, Jual del	Liége, Belgium.
Carter, William Arthur Philip	Sheffield.
Clayton, John Herbert	Scunthorpe, Lincs.
Cuthbert, James Richard	Brigg, Lincs.
Dod, Michael Henry Anthony	Scunthorpe, Lincs.
Doncaster, Richard Tobey	Sheffield.
Dougan, Charles William	Alabama, U.S.A.
Down, Lawrence Frank	Scunthorpe, Lincs
Dunlap, Gordon Erskine	Worcester, Mass., U.S.A.
Durán, Rafael Ortega	Liége, Belgium.
Eng, Jim, B.S.	Syracuse, N.Y., U.S.A.
Eppelsheimer, Daniel Snell, B.S., D.Sc.	Middletown, Ohio, U.S.A.
Fox, Reginald, Assoc.Met.	Rotherham.
Frederick, Sidney Hamilton	Sheffield.
Gillis, Gordon H.	Granite City, Ill., U.S.A.
Goffe, John Edward	Sheffield.
Hall, William Patrick	Scunthorpe, Lincs.
Harris, Arthur Charles, jun.	Buffalo, N.Y., U.S.A.
Hesselwood, William Campbell	Sheffield.
Jackson, Walter	Scunthorpe, Lincs.
Kilby, Donald	Middlesbrough.
Lingard, L. M.	Sheffield.
Lismer, Roy Edward	Sheffield.
Loewy, Max Rudolf	Sheffield.
Luke, Richard Forsyth	Workington, Cumberland.
Mackay, Ronald Peter Alistair	Porthcawl, Glam.
McReynolds, Elmer Loren	Massillon, Ohio, U.S.A.
Martin, James Leo	Lowell, Mass., U.S.A.
Padbury, Henry Frank	Swansea.
Phillips, Robert Metcalf	Cleveland, Ohio, U.S.A.
Rhines, Frederick N., Ph.D.	Pittsburgh, Pa., U.S.A.
Richardson, Thomas Compton	Sheffield.
Riley, Derick Newton	Aylsham, Norfolk.
Robinson, Raymond George Lowe	St. Helens, Lancs.
Rutherford, John James Brown	Kearny, N.J., U.S.A.
Sadler, Hubert	Sheffield.
Sandelin, Robert William	Georgia, U.S.A.
Slater, Peter	Sheffield.
Smith, Eric John Charles	Sheffield.
Stonehouse, Basil Hugh	Bowdon, Cheshire.

SWIFT, GEORGE P.	Cambridge, Mass., U.S.A.
TROTTER, WILLIAM LANCELOT .	Scunthorpe, Lincs.
TYE, GEORGE ARCHER . .	Tucson, Arizona, U.S.A.
WILMORE, GEORGE WILLIAM .	Scunthorpe, Lincs.

PROPOSED AUTUMN MEETING OF THE INSTITUTE AT DÜSSELDORF, SEPTEMBER, 1936.

THE PRESIDENT (Sir HAROLD CARPENTER, F.R.S.) said that at the meeting held in Manchester he had announced that the Council had accepted an invitation from the Verein deutscher Eisenhüttenleute, on behalf of the German Iron and Steel Industry, to hold the Autumn Meeting in Düsseldorf. The date which had been agreed upon was from September 20 to September 27 inclusive, with an extension to September 30 for parties visiting certain other places. It was estimated that the inclusive cost of the main visit would be about £20. He would ask Dr. Petersen, whom the Institute welcomed at its meeting that day, to convey the invitation to the members.

Dr. OTTO PETERSEN (Director of the Verein deutscher Eisenhüttenleute) said he would like to thank the Institute for the reception given to him in this country as the representative of the Verein deutscher Eisenhüttenleute and the German Iron and Steel Industry. When a metallurgist who had some knowledge of history came to England, he was always struck by the recollection of the great English pioneers in the field of metallurgy. To begin with, there was Henry Cort. It was of interest that two Christian names of the present President of the Institute were Henry Cort, and it was significant that those names should be borne by one who had achieved an international reputation in metallurgy. In the direct line from Henry Cort came Sir Henry Bessemer, and then Sidney Gilchrist Thomas. It sounded like a fairy tale to hear that morning that Mr. Thomas' cousin, who, in conjunction with Thomas, invented the great process associated with his name, died only last year. What Thomas meant for Germany was well known; he was the foundation on which had rested the development of the German Iron and Steel Industry since 1880.

Personally, he had taken advantage of his visit to see some of the British iron and steel works. He had been very interested to see the new plant at Corby and two model plants in the neighbourhood of Scunthorpe. At Corby the memory of Thomas was being revered by putting in what was a development of the Thomas process, and that was of great interest to German metallurgists, who were going ahead on the same lines.

He found in England sunshine and the green of spring in a prosperous and happy land. He believed that the production of this country was increasing, and that a production of about eleven

million tons of steel was expected for the present year, the highest figure reached in the history of steel-making in England.

It was his duty and pleasure to convey an official invitation from the Verein deutscher Eisenhüttenleute on behalf of the German Iron and Steel Industry to the Institute to visit Düsseldorf and to make that their headquarters and to see all the places of interest in the neighbourhood—the gentlemen on the metallurgical side and the ladies on the other side. The President and Members of the Council of the Institute knew the programme that was proposed for the visit, and the German metallurgists looked forward to the honour of a visit from the Institute with pleasure and interest.

It was fitting that Sir Harold Carpenter should lead the Institute party to Düsseldorf, for Sir Harold had been a student at Leipzig and took the degree of Doctor of Philosophy in Germany. That was a good omen for the success of the meeting.

In conclusion he would say : Come ! Come all, and see ! *Auf Wiedersehen in Düsseldorf !*

THE PRESIDENT said he was sure all the members would wish him to thank Dr. Petersen very much for his delightful address. He assured Dr. Petersen that the members of the Institute were looking forward very much to their visit to Düsseldorf. He hoped there would be a splendid attendance there of members of the Institute, and he thanked Dr. Petersen for the trouble that he had already taken to make such interesting arrangements for the visit.

ELECTION OF VICE-PRESIDENTS AND MEMBERS OF COUNCIL.

The following retiring Vice-Presidents and Members of Council were re-elected :

Vice-Presidents.—Mr. A. Hutchinson, Mr. John Craig, and Mr. H. Spence Thomas.

Members of Council.—The Earl of Dudley, Captain Robert S. Hilton, Mr. I. F. L. Elliot, Mr. E. F. Law, and Dr. T. Swinden.

PRESENTATION OF THE BESSEMER GOLD MEDAL TO MR. FRED CLEMENTS.

THE PRESIDENT (Sir HAROLD CARPENTER, F.R.S.) said it was his pleasant duty to make the award of the Bessemer Gold Medal, which was the highest honour that the Institute was able to confer. He felt sure that all the members would agree that in selecting Mr. Fred Clements the Council had made a wise and happy choice. (*Applause.*) Mr. Clements had been associated for many years with the Park Gate Iron and Steel Company, and there could be no doubt that he was largely responsible for the favourable position in which the Company found itself to-day. He was a practical metallurgist, but not one of the so-called practical men who had

no use for science. He had always realised and utilised the benefits which science could confer on industry, and, indeed, he himself had made valuable contributions to the science of ferrous metallurgy.

Mr. Clements became a member of the Institute in 1920, and between that date and the year 1923 he published three papers of exceptional merit dealing with the three main units of iron and steel production : The blast-furnace, the open-hearth steel furnace, and the gas producer. The theme of his papers was heat economy achieved by applying the methods of thermo-chemical analysis to metallurgical problems. The papers were received, as they deserved to be received, with keen interest both in this country and abroad, and it was not an exaggeration to say that they made Mr. Clements' reputation and enhanced that of the Institute. Since then Mr. Clements had not produced any more papers, but he had made many distinguished contributions to the discussions of papers dealing with iron and steel processes and appliances, and he had served the Institute well as a valued member of the Council since 1930 and as a member of several Committees. In 1929 Mr. Clements published his famous book on blast-furnace work, with which all the members were familiar. The three volumes were lengthy, because they were intended to form a complete record of the scientific and practical knowledge concerning the many aspects of iron production. The book was a sequel to Mr. Clements' first paper. Most men would be delighted to regard such a book as a life's work, but he was sure that all the members of the Institute hoped that Mr. Clements would not be content until he had given a similar sequel to his later papers on steel production.

He asked Mr. Clements to accept the Medal as a token of the Institute's appreciation of the services he had rendered to the Iron and Steel Industry.

THE PRESIDENT then, amid applause, presented the Bessemer Gold Medal to Mr. Clements.

Mr. FRED CLEMENTS, in reply, said he felt it was quite impossible for him to express adequately his appreciation of the very great honour the Institute had conferred upon him. As he recalled the names of those who were enrolled upon the list of Bessemer Gold Medallists, the fact that he had been deemed worthy to join their ranks made him very proud by its inference but indeed very humble also.

It was difficult for him to know what to say, but he would like to be reminiscent for a few moments. He was by instinct and training an engineer. He thought he had been born with a mathematical mind and with manipulative skill in his fingers. From his earliest days, as far back as he could remember, he always knew what he was going to be, without very much realisation of what it

meant and still less hope of ever achieving it. His domestic circumstances and the early death of his father made it necessary for him at the age of 14 to begin to earn his living, and his ambition had to be satisfied with a job as a fitter's apprentice in the works of Markham & Co., Ltd., of Chesterfield. He had to be up at 5 o'clock in the morning in order to get to work at six, and he learned to live laborious days in trying to achieve some measure of education alongside his daily work.

That training, however, persisted until this day. His skill as a young mechanic brought him to the notice of Mr. Charles Markham, who unlatched the door of opportunity for him. Primarily Mr. Markham did nothing more, but when he found that he was capable of pushing that door open he encouraged him to pass through it to the possibilities that lay beyond it. Mr. Markham gave him a chance in his drawing office, and when he was about 20 years of age Mr. Markham sent him to a junior post in the drawing office of the Park Gate Company, of which he was a Director. Mr. Frank Dick, who would be known to many present that morning, was the General Manager of the Company at that time, and he had the privilege of working under him for several years, until Mr. Dick's death. In 1905 he won the Whitworth Exhibition and Medal, and that Exhibition enabled him to carry his technical education to a useful level in the newly formed Sheffield University. Mr. Markham, who was a major force in Park Gate affairs, then began to give him his confidence, and, although he was still a young man, the various schemes which Mr. Markham's powerful personality and keen and energetic mind evolved were frequently passed over to him to examine technically and to bring, if possible, to a practical issue. The interests covered a very wide range. There were problems in coal mining, in coke manufacture, in chemicals, in engineering, and in iron and steel production. He therefore gained a very useful experience, because in most cases new ground was being broken, which involved the examination of all the data available and the utilisation of a good deal of original thought in their application.

He had given that short narrative of his work because he wished to acknowledge the debt that he owed to his late chief, Mr. Charles Markham. He could conceive of nothing which would have given greater pleasure to Mr. Markham than to know that one of his boys had been deemed worthy to receive the Bessemer Gold Medal. (*Applause.*)

It was, however, the problems of iron and steel manufacture which interested him most, especially in view of his growing responsibilities to the Park Gate Company in the design of new plant. He soon realised that there were great gaps in the existing information and a good many inconsistencies in what did exist. It became apparent that a new examination of the main factors in iron and steel production was necessary. For a matter of four or five years

that was carried out—and a very big task it was. The difficulties were tremendous. He confessed that he had frequently laid it aside with a sense of utter despair. However, he persisted in the work, and eventually the papers to which the President had kindly referred were published and found favour in many countries. After that, his dream grew bigger. He had visions, as the President had indicated, of dealing with the main items of iron and steel production on a very much bigger scale. However, it was the blast-furnace side which interested him most and which he tackled primarily, because the problems therein were such that direct measurement was in some cases not possible and deductions could be made only by inference, by consideration of the thermal, chemical, and physical data. All the time that he could spare from the duties of his office was devoted, for a matter of five years, to blast-furnace work. His early training in living laborious days stood him in good stead. He was frequently at his desk at 5 o'clock in the morning, and when he arrived home in the evening he spent three or four hours in dictating matter to his typist. Unfortunately, during that period he was in almost continuous physical pain. That was now, happily, a thing of the past, but it was a very real factor at that time, and it was due only to the unremitting care of his wife that he was able to carry on. (*Applause.*) In addition, Mrs. Clements took over the task of reading and correcting the typescript and the compiling of the very complete index with which each volume was furnished. If, as the President had inferred, the industry owed any debt to him, a large part of that debt was owing to his wife. (*Applause.*) At length the task was finished, and the reception which the book received throughout the world was, to say the least, gratifying. His dream, however, was not then fulfilled. There was still the steel side of the industry to be dealt with, but the gigantic task which that involved was too much for him, because he had to turn aside somewhat reluctantly and give his attention to the executive side of the industry.

As all the members knew the industry had been passing through a very difficult time from 1923 until to-day. In 1923 he was appointed General Manager of the Park Gate Company, and it was through the difficult period to which he had referred that he had had to try to conduct its affairs. He had been appointed a Director last year. It was during that difficult period that he felt, as he looked back, that he had been able to do his best work, certainly from the human point of view. He said that because it had been his effort to try to create an organisation each member of which, within the limits of his job, would feel that he was encouraged to express himself and to contribute his quota of original thought and effort to the welfare of the firm and the progress of the industry.

He had given a personal narrative on the present occasion not because he liked talking about himself, for he really disliked doing

so very much, but because he wanted to bring home to the members of the Institute the circumstances out of which had emerged the work to which the President had been good enough to refer.

Further, he would like to speak to the younger members of the Institute. He would like to call their attention to the great fields that had still to be investigated, and he would say that at no time, in no country and in no industry had there ever been the opportunities that there were to-day in the iron and steel industry. But opportunity, like the pearl of great price, did not come unsought; it was the reward of the earnest seeker. At the same time he would like to say to those present who were the executive heads of large firms: Do not quench the spark of original thought or effort in any of your people. Original thought was too uncommon for anyone to do that. The spark, such as it was, might appear in unexpected places. It should be shielded with sympathy and fanned with the breath of encouragement. If it was false it would die; if it was true it would live and glow, and might set alight a blaze in the world of thought.

The attitude adopted towards industrial life should not be to think what one could get out of it but to think what one could put into it. That might seem unsound, altruistic and idealistic, but it was true. In all the divergencies and antagonisms of industrial life he saw nothing but a sense of mutual service which could act as that magic thread of gold by which all could be bound together.

He accepted the Medal not only in his own name but in the name of all those who were trying, by spending themselves, by labour of mind or labour of body, to increase and improve the technical progress of the great world-wide iron and steel industry, for it was to them as well as to himself that he deemed the award to be given. In their name and in his own he said, with all sincerity: We thank you. (*Applause.*)

Presentation of the Andrew Carnegie Gold Medal for 1935.

The President (Sir Harold Carpenter, F.R.S.) announced that the Andrew Carnegie Gold Medal for 1935 had been awarded to Dr. D. F. Marshall, of Sheffield, for his paper entitled "Further Determinations of the External Heat Loss of Blast-Furnaces." That paper contained an account of a research carried out with the aid of a grant from the Andrew Carnegie Research Fund, and was published in the No. I. *Journal of the Iron and Steel Institute* for 1935. The subject of the paper was one to which Mr. Clements had referred, a particularly happy coincidence.

The President then, amid applause, presented the Andrew Carnegie Gold Medal to Dr. Marshall.

Dr. D. F. MARSHALL, in reply, said he felt somewhat overawed at following in the footsteps of so famous a man as Mr. Fred Clements. If he thought for one moment that he would follow along the road which Mr. Clements had taken he would feel that he really deserved the Medal. He would like to express his sincere appreciation of the honour the Council had bestowed upon him. Three years ago they made him a grant to enable him to carry out the research in question and at that time he felt proud of the honour done him by so famous a body as the Iron and Steel Institute. He hardly knew how to express his feelings on receiving the Medal. He thought he could crystallise them in one statement, namely, that no student could receive a greater incentive to work hard than that of receiving from the members of the Institute the encouragement, advice, and practical assistance which had been so freely given to him.

WILLIAMS PRIZE.

THE PRESIDENT (Sir HAROLD CARPENTER, F.R.S.) said there had been no award of the Williams Prize for the past year, and he had been asked to draw the attention of members to the Prize. It was intended as a reward to younger workers engaged in the iron and steel industries in a position not superior to that of manager of any one technical department. The Council felt that a good deal more advantage might be taken of the Prize than had so far been the case, and he would appeal to chiefs of staffs who were in charge of possible competitors to facilitate investigations which would lead to the production of papers of the type required. The late Mr. Williams, the founder of the Prize, had had very much at heart papers of the type presented by young practical workers, and there had not been as yet anything like the response for which Mr. Williams had doubtless hoped. He trusted, therefore, that chiefs of staffs would encourage their younger workers to come forward with papers of the type in question.

ANDREW CARNEGIE RESEARCH SCHOLARSHIPS.

THE SECRETARY announced that applications for grants had been received from twenty-three candidates, and, after careful investigation of all the applications, the Council had decided that grants of the amounts stated below (total value, £1000) be awarded to the following applicants :

T. RAINE (The University, Sheffield).—£75 in aid of work on the determination of oxygen in steel. (Third grant.)

J. B. VICKERS (The University, Sheffield).—£75, in aid of work on the determination of oxygen in steel. (Second grant.)

G. T. RICHARDSON (The University, Leeds).—£50, in aid of a research on the influence of varying atmospheres on steels. (Second grant.)

W. HOOK (Armstrong College, Newcastle-on-Tyne).—£50, to study the pyrolysis of organic compounds with a view to the determination of factors which favour graphite formation. (Second grant.)

H. A. MILEY (The University, Cambridge).—£100, in aid of a research on the thickness of thin oxide films on iron and the law of growth at ordinary temperatures.

(The above researches will be carried out on behalf of Research Committees of the Institute and the Iron and Steel Industrial Research Council.)

G. M. DYSON (Loughborough College).—£50, in aid of a research on the adsorption of gases by cast iron and steel and their diffusion throughout these materials.

HANS ESSER (Institut für Eisenhüttenkunde der Technischen Hochschule Aachen).—£100, in aid of a research on the true structure of metals.

ERIC W. FELL (Manchester University).—£50, in aid of a research on the breakdown of elastic behaviour in steel and its avoidance.

ROOSEVELT GRIFFITHS (University College of Swansea).—£50, to study some fundamental aspects of the scaling of iron and steel.

LEON GUILLET, jun., and PAUL G. BASTIEN (École Centrale des Arts et Manufactures de Paris).—£100, in aid of a research on the influence of some special elements on certain properties of cast irons.

OTTO REIF (Eisenhüttenmännisches Institut der Technischen Hochschule Berlin).—£100, in aid of a research on the scaling of iron and metals.

WILLIAM S. WALKER (College of Technology, Manchester).—£50, in aid of a research on quantitative thermal analysis.

JAMES WHITE (Royal Technical College, Glasgow).—£100, in aid of a research on equilibria at high temperatures in systems containing ferric oxide.

C. BOOTH (The University, Sheffield).—£50, in aid of investigations on basic refractories with particular reference to their use in linings of induction furnaces. (Second grant.)

P. T. CARTER (Armstrong College, Newcastle-on-Tyne).—£50 for an investigation of the properties of graphite (granted subsequently).

Bo O. W. L. LJUNGGREN (Metallografiska Institutet, Stockholm).—£100 for a research on the microsclerometric investigation of grain boundaries (granted subsequently).

PAPERS PRESENTED.

The following papers were presented for discussion :

C. O. BANNISTER and R. RIGBY.—" The Influence of Light on the Electrode Potential and Corrosion Phenomena of Mild Steel."

M. L. BECKER and C. E. PHILLIPS.—" Internal Stresses and their Effect on the Fatigue Resistance of Spring Steels."

C. BENEDICKS.—" Electrical Resistivity of Faraday Steels; Gas Analysis and new Phenomena on Remelting in Radiation Furnace."

C. A. EDWARDS, F.R.S., and OTHERS.—" A Study of the Influence of Varying Degrees of Cold-Rolling and Annealing Temperatures on the Properties of Mild Steel Sheets." Part I.—" The Influence of Cold-Rolling and Subsequent Annealing Temperatures on the Erichsen Values and Crystal Structure of Thin Mild Steel Sheets," by C. A. Edwards, F.R.S., D. L. Phillips, and W. H. E. Gullick. Part II.—" The Effects of Varying Degrees of Cold-Rolling and Annealing Temperatures on the Properties of Motor Car Body Sheets," by C. A. Edwards, F.R.S., D. L. Phillips, and C. R. Pipe.

W. E. GOODRICH.—" The Embrittlement of High Tensile Alloy Steels at Elevated Temperatures."

G. A. HANKINS, M. L. BECKER, and H. R. MILLS.—" Further Experiments on the Effect of Surface Conditions on the Fatigue Resistance of Steels."

T. P. HOAR and D. HAVENHAND.—"Factors Influencing the Rate of Attack of Mild Steels by Typical Weak Acid Media."

A. W. HOTHERSALL and W. N. BRADSHAW.—"Methods of Detinning Tinplate for Examination of the Thickness and Continuity of the Alloy Layer."

A. W. HOTHERSALL and J. C. PRYTHERCH.—"A Study of the Origin of Porosity in the Tin Coating of Tinplate."

E. MAURER and W. BISCHOF.—"The Distribution of Sulphur between Metal and Slag in the Basic and Acid Processes of Steel Manufacture."

G. A. V. RUSSELL.—"Some Considerations Influencing Plant Facilities for Strip-Sheet Production under British Conditions."

H. J. TAPSELL, M. L. BECKER, and C. G. CONWAY.—"The Behaviour of Five Cast Irons in Relation to Creep and Growth at Elevated Temperatures."

J. H. WHITELEY.—"A Survey of the Iron-Carbon Diagram near Zero Carbon (below 1000° C.)."

The following Special Reports were also published at the time of the Meeting:

"The Work of the Corrosion Committee," by W. H. HATFIELD, F.R.S. (Chairman). (Special Report No. 11.)

"The Work of the Heterogeneity of Steel Ingots Committee," by W. H. HATFIELD, F.R.S. (Chairman). (Special Report No. 12.)

Discussion, Correspondence, and Reply on "Sixth Report on the Heterogeneity of Steel Ingots" (Special Report No. 9A).

Discussion, Correspondence, and Reply on "Waste-Heat Boilers in Open-Hearth Practice" (Special Report No. 10A).

VOTES OF THANKS.

To the Institution of Civil Engineers.

THE PRESIDENT moved a vote of thanks to the President and Council of The Institution of Civil Engineers for placing their lecture theatre at the disposal of the Institute for the meeting. He had attended the May Meetings of the Institute for thirty-five years, and he believed that on every occasion the Institute had met in the building of The Institution, first in the old building on the other side of Great George Street and later in the present one. The members of the Institute, he was sure, greatly appreciated the comfort and convenience which the accommodation provided afforded.

Dr. W. H. HATFIELD, F.R.S. (Vice-President), seconded the motion, which was carried unanimously.

To the President.

On the motion of Professor HENRY LOUIS, M.A., D.Sc. (Past-President), a cordial vote of thanks to the President for presiding, as Professor Louis said, with his usual kindness and urbanity, was carried by acclamation.

The proceedings then terminated.

REPORT OF COUNCIL.

H.M. King George V.

It is with the deepest regret that the Council record the death of His Majesty King George V. His Majesty had been an Honorary Member of the Institute from 1905 until his accession in 1910, when he had become Patron of the Institute. In 1934 he had accepted the Bessemer Gold Medal as a further sign of the constant interest which, throughout his life, he had shown in the welfare of the Industries and Sciences which it is the object of the Institute to serve.

At a Meeting of the Council held on the 26th February, 1936, it was resolved to send the following address to His Majesty King Edward VIII. :

To His Most Excellent Majesty King Edward VIII.

May it please Your Majesty—

We, Your Majesty's loyal, attached and dutiful servants, the President and Council of the Iron and Steel Institute, to-day assembled at a Meeting of the Council, desire to be permitted to offer to Your Majesty, to Her Majesty Queen Mary, and to the other Members of the Royal Family, this expression of the profound sympathy which we and all the members of the Iron and Steel Institute feel in the irreparable loss which has befallen Your Majesty and the whole Empire through the death of Our Beloved Sovereign Lord, King George, Patron of the Institute.

The members of the Iron and Steel Institute share the deep and heartfelt sorrow of all Your Majesty's subjects at the loss of a Sovereign who throughout his reign was unremitting in his devotion to the welfare of his peoples. They are proud to remember that His Majesty, at the time of his accession, was graciously pleased, as a mark of

his royal favour, to become the Patron of this Institute, having previously for five years been an Honorary Member. Further, His Majesty was in 1934 pleased to accept the Bessemer Gold Medal which was offered as a humble expression of appreciation of the constant and warm interest shown by him in the welfare of the industries represented by this Institute. Those of our officers who were then privileged to be received by His Majesty will never forget the keen and lively interest which he showed in the activities of this Institute.

YOUR MAJESTY was also in 1919 graciously pleased to accept Honorary Membership of this Institute and we venture to take this occasion dutifully to offer to Your Majesty this expression of our heartfelt congratulations and of our loyal homage and devotion.

Given under the Seal of the Iron and Steel Institute this twenty-seventh day of February in the Year of our Lord One Thousand Nine Hundred and Thirty-Six.

(*Signed*) H. C. H. CARPENTER, *President.*
(*Signed*) KENNETH HEADLAM-MORLEY, *Secretary.*

The following reply was received from His Majesty's Secretary of State for Home Affairs :

HOME OFFICE,
WHITEHALL,

17*th March*, 1936.

SIR,

I have had the honour to lay before The King the Loyal and Dutiful Address of the President and Council of the Iron and Steel Institute on the occasion of the lamented death of His late Majesty King George the Fifth and have received The King's Commands to convey to you His Majesty's grateful Thanks for the assurances of sympathy and devotion to which it gives expression.

I am,
Sir,
Your obedient Servant,

(*Signed*) JOHN SIMON.

The President,
The Iron and Steel Institute.

Patronage of the Institute.

The Council are proud to announce that His Majesty King Edward VIII. has been graciously pleased to become Patron of the Institute.

The following letter was, by order of the Council, addressed to the Right Hon. Lord Wigram of Clewer, P.C., G.C.B., G.C.V.O., C.S.I., Keeper of the Privy Purse :

25th March, 1936.

My Lord,

We are desired by the Council of the Iron and Steel Institute to ask you to submit to His Majesty King Edward VIII. a humble and loyal request that His Majesty will be graciously pleased to honour the Iron and Steel Institute by consenting to become its Patron.

The Council of the Iron and Steel Institute in submitting this request recall with pride that His Majesty has been an Honorary Member of the Institute since 1919.

His Majesty King Edward VII. and His Majesty King George V. honoured the Institute by becoming Patrons, and they were also graciously pleased to accept the Bessemer Gold Medal in 1906 and 1934 respectively, while Her Majesty Queen Victoria was also graciously pleased to accept the Bessemer Gold Medal in 1899.

In transmitting this request we are desired to ask you to assure His Majesty of the loyalty and devotion of the Members and Council of this Institute.

We have the honour to remain,

Yours faithfully,

(*Signed*) H. C. H. Carpenter, *President.*
(*Signed*) Kenneth Headlam-Morley, *Secretary.*

The following reply was received :

Privy Purse Office,
Buckingham Palace,
S.W.

6th April, 1936.

Dear Sir,

I am commanded by The King to inform you that His Majesty has been graciously pleased to grant his Patronage to The Iron and Steel Institute.

Yours truly,

(*Signed*) Wigram,
Keeper of the Privy Purse.

The President,
The Iron and Steel Institute,
28, Victoria Street,
S.W.1.

The Annual Report.

The Annual Report of the proceedings and work of the Iron and Steel Institute during the year 1935 is submitted by the Council for the approval of members at this, the Sixty-Seventh Annual General Meeting.

Roll of the Institute.

During the past year one hundred and four new members and seventeen associates were elected; seven associates were transferred to membership, and six members were reinstated. Forty-two members and one associate resigned their membership during the year. The total membership of the Institute on the register on December 31, 1935, was accordingly as follows:

Patron	1
Honorary Members	17
Life Members	67
Ordinary Members	1768
Associates	62
	1915

This total compares with 1918 at the end of the previous year.

The Council regret to record the deaths of the following twenty-eight members of the Institute which occurred during the year 1935:

Ajuria, C. (Vitoria, Spain)	August.
Beale, Sir John Field (London) (Life Member)	December 9.
Bramley, A. (Loughborough)	July 19.
Davies, W. R. (Cardiff)	May 15.
Ewing, Sir J. A. (Cambridge)	January 7.
Finnie, W. (Aberdeen)	January.
Gilchrist, P. C. (London) (Life Member, Hon. Vice-President)	December 15.
Harding, R. C. (Newport)	September.
Hiby, W. (The Hague, Holland)	November 18.
Hipkins, W. (Birmingham)	April.
Hunting, F. F. (Cardiff)	April 27
Hyslop, Sir R. Murray (London)	September 12.
Kitching, J. (Darlington)	March 28.
Kitson, F. J. (Leeds)	November 19.
Lothrop, M. T. (Canton, Ohio)	May 24
McCosh, W. W. (Airdrie)	March 17.
Mackenzie, T. B. (Glasgow) (Life Member)	August 5.
Mathews, J. A. (New York)	?

Mitchell, P. J. (London) (Life Member). .	September 13.
Neilson, J. (Glasgow) (Original Member).	July.
Ohlsson, O. (San Sebastian) . . .	June 26.
Patterson, S. R. (Cardiff) . . .	February 23.
Peech, J. E. (London)	October 7.
Ritchie, R. J. H. (Marton-in-Cleveland) .	?
Rollason, J. (Birmingham) . . .	December 2.
Thomas, J. (Kidwelly, Carm.) . .	April 26.
Waterston, R. (Helensburgh). . .	?
Webb, H. A. (Stourbridge) . . .	?

The deaths of the following nine members took place before 1935, but have not been previously reported :

Barber, E. (Sheffield)	May, 1934.
Dunnachie, J. (Glenboig, Scotland) .	June 4, 1934.
Hayne, W. Crosier (London) . .	December 18, 1934.
Jansson, G. (Stockholm) . . .	?
Jobson, R. H. T. (Varberg, Sweden) .	October 29, 1934.
Morgans, J. T. (Mold, Flints) . .	September 9, 1934.
Orueta, José de (Renteria, Spain) . .	November 19, 1934.
Proctor, W. H. W. (Coventry) . .	December 18, 1934.
Sweet, H. N. (Dover, Mass.) (Life Member)	?

The Council wish to place on record their regret at the death, after illness lasting for many years, of Mr. Percy Carlyle Gilchrist, F.R.S. Mr. Gilchrist's name is honoured throughout the world for his work, in conjunction with his cousin, Mr. Sidney Gilchrist Thomas, on the invention of the basic process of steelmaking, the success of which was first established at the works of Messrs. Bolckow Vaughan & Co., Ltd., at South Bank, near Middlesbrough, in April 1879. From their joint invention originated the basic Bessemer and the basic open-hearth processes of steel manufacture, by means of which an overwhelming proportion of the world's steel is now produced. Mr. Gilchrist joined the Institute in 1875; in 1884 he was elected a Member of Council, in 1898 a Vice-President, and in 1916 an Honorary Vice-President.

Mr. J. Neilson was the last Original Member of the Institute, and Sir John Field Beale, K.B.E., Mr. T. B. Mackenzie, Mr. P. J. Mitchell and Mr. H. N. Sweet were Life Members.

Finance.

The Statement of Accounts for the year 1935, which has been duly audited and certified by Messrs. W. B. Keen and Co., the Institute auditors, accompanies this Report, and is presented by Mr. James Henderson, the Hon. Treasurer, for approval at the Meeting.

The ordinary income of the General Fund during 1935 was

£8788 16*s.* 9*d.*, and the expenditure £10,721 8*s.* 5*d.*, the result being an excess of expenditure over income of £1932 11*s.* 8*d.* The receipts of the Special Appeal Fund during the year amounted to £2010, and this figure has been taken into the Accounts. The sum of £50 has been transferred to the Reserve Account for the preparation of the Ten-Year Index, so that the final excess of income over expenditure is £27 8*s.* 4*d.*, and this amount has been carried to the Balance Sheet.

Entrance Fees, amounting to £201 5*s.* 0*d.*, received during the year have not been included in income as has formerly been the case, but have been transferred to Reserve Account.

The Accounts of the Welding Symposium are shown separately; the balance of the Income and Expenditure Account at the end of the year was an excess of expenditure over income of £1244 8*s.* 3*d.* Two thousand copies of the Proceedings were printed. The unsold stock of volumes has not been valued, and the proceeds of further sales will be available for reducing this sum. It is estimated that if the remaining stock is disposed of, the ultimate net cost to the Institute will be reduced to about £300; 822 sets of volumes were sold before publication in November, 1935, and 450 additional sets since then up to the end of March, 1936. Sales are continuing at a satisfactory rate.

The Council have thought it prudent to adopt as conservative a policy as the financial situation will permit, and with this object have maintained and increased the reserves of the Institute. In the Balance Sheet are included Suspense Accounts, which total £1251 5*s.* 0*d.*, and are composed of £1000 contributions to the Special Appeal Fund, held in suspense and brought forward from the Balance Sheet last year, £201 5*s.* 0*d.*, Entrance Fees not included in the Income and Expenditure Account, as mentioned above, and provision towards the cost of publishing the Ten-Year Index, £50. In addition, under the heading of Capital and Reserve Account is included a reserve, being accumulated excess of income over expenditure of £929 8*s.* 2*d.* In accordance with usual practice, subscriptions in arrears, the stock of Journals, office furniture and the Library have not been valued.

A separate schedule of investments shows that the market value of the investments of the General Fund of the Institute was, at the 31st December, 1935, £28,212 3*s.* 4*d.*, as against £23,873 12*s.* 4*d.*, cost price, at which they are included in the Balance Sheet.

The substantial receipts during the past three years of the Special Appeal Fund have had an important effect on the financial situation of the Institute. Only by their assistance has it been possible to meet expenditure out of current income. Unless an income of at least £2000 a year is assured from this source it will not be possible for the activities of the Institute to be maintained and extended in the best interests of the members and of the Industry. It is for this reason that the Council acknowledge, with

satisfaction, the willingness of a number of companies to continue their subscriptions and of others, which had not previously subscribed, to give this practical sign of appreciation of the value of the Institute to the Industry.

The Council wish to take this opportunity of again recording their appreciation of the generous subscriptions which they have received from individuals, companies, and associations. The following is the list of subscribers to the Special Appeal Fund up to the 31st December, 1935 :

Baldwins, Ltd.
Barrow Hematite Steel Co., Ltd.
Mr. Cyrus Braby.
Frederick Braby & Co., Ltd.
Guest Keen Baldwins Iron & Steel Co., Ltd.
Colvilles, Ltd.
Consett Iron Company, Ltd.
Newton Chambers & Co., Ltd.
Darwen & Mostyn Iron Co., Ltd.
Dorman, Long & Co., Ltd.
Thos. Firth & John Brown, Ltd.
Guest, Keen & Nettlefolds, Ltd.
Hadfields, Ltd.
Sir Robert Hadfield, Bt., F.R.S.
Imperial Chemical Industries, Ltd.
Lancashire Steel Corporation, Ltd.
John Lysaght, Ltd.
Park Gate Iron & Steel Co., Ltd.
Sheet Makers' Conference.
South Durham Steel & Iron Co., Ltd., and Cargo Fleet Iron Co., Ltd.
South Wales Siemens Steel Association.
Stanton Ironworks Co., Ltd.
Staveley Coal & Iron Co., Ltd.
Steel Company of Scotland, Ltd.
Stewarts & Lloyds, Ltd.
John Summers & Sons, Ltd.
Richard Thomas & Co., Ltd.
United Steel Companies, Ltd.
Vickers, Ltd.
Welsh Plate & Sheet Manufacturers' Association.
Colonel Sir W. Charles Wright, Bt., K.B.E., C.B.

The Accounts of the Carnegie Research Fund, Bessemer Medal Fund, and Williams Prize Fund, having been duly audited, are also presented in the usual form.

Silver Jubilee of H.M. King George V., 1935.

The year was chiefly memorable for the Silver Jubilee of H.M. King George V. On the occasion of the celebration of the completion of the twenty-fifth year of his reign on May 6th, 1935, fifteen Engineering Institutes in Great Britain combined to send a Loyal Address of congratulations and devotion to His Majesty. The following is the text of the address :

To the King's Most Excellent Majesty.

May it please Your Majesty,

We, as representatives of and on behalf of the principal Engineering Institutions and Societies in the United Kingdom of Great Britain and Northern Ireland, humbly beg leave to convey to your Majesty the Loyal Greetings and Felicitations of our 67,000 Members upon the attainment of the 25th Anniversary of Your Majesty's accession to the Throne.

Through Your Majesty's wise and beneficent rule and encouragement of Science in Industry, the utilisation of the great sources of power in Nature has been advanced to an extent unprecedented in the history of mankind, thus contributing in no small degree to the welfare of all Your Majesty's subjects.

We desire to express our deep loyalty and devotion and our high appreciation of the work Your Majesty has done towards the promotion of the Science and Art of Engineering in its bearing on the well-being of the Empire.

We pray that Your Majesty may live long to enjoy good health and happiness.

The Institution of Civil Engineers (1818).
The Institution of Mechanical Engineers (1847)
The Institution of Naval Architects (1860)
The Institution of Gas Engineers (1863)
The Iron and Steel Institute (1869)
The Institution of Electrical Engineers (1871)
The Institution of Municipal and County Engineers (1873)
The Institute of Marine Engineers (1889)
The Institution of Mining Engineers (1889)
The Institution of Mining and Metallurgy (1892)
The Institution of Water Engineers (1896)
The Institution of Automobile Engineers (1906)
The Institute of Metals (1908)
The Institution of Structural Engineers (1908)
The Institution of Chemical Engineers (1922)

The following acknowledgment was received by the Iron and Steel Institute :

Home Office,
Whitehall.
17*th May*, 1935.

Sir,

I am directed by the Secretary of State to inform you that he has been Commanded by The King to convey His Majesty's thanks to the

fifteen Engineering Institutions and Societies for their Address of Congratulation presented to His Majesty on the completion of the Twenty-fifth Year of His Reign. His Majesty much appreciates this expression of loyalty and devotion in which the President, Officers and Members of The Iron and Steel Institute have joined.

I am,
Sir,
Your obedient Servant,
(*Signed*) H. A. STRUTT.

The Secretary,
The Iron and Steel Institute,
28, Victoria Street,
S.W.1.

The Illuminated Address was followed by sheets bearing the Corporate Seals and the signatures of the Presidents and Secretaries of the participating Societies.

BESSEMER GOLD MEDAL.

The Bessemer Gold Medal for the year 1935 was presented to Professor A. M. Portevin, Director of the Institut de Soudure Autogène, Professor at the École Supèrieure de Fonderie, and at the École Centrale des Arts et Manufactures, Paris, in recognition of his contributions to the advancement of the science and practice of metallurgy.

CHANGES ON THE COUNCIL.

Induction of New President.—At the Annual General Meeting in May 1935, Sir Harold Carpenter, F.R.S., was inducted President in succession to Mr. W. R. Lysaght, C.B.E.

Other Changes.—In the Report of Council for 1934 (see *Journal of the Iron and Steel Institute*, 1935, No. I., p. 8) it was stated that the election of members of Council to fill three vacancies which had occurred in that year had been deferred. During the year now under review (1935), Mr. I. F. L. Elliot, Mr. E. F. Law, and Dr. T. Swinden were elected Members of Council. Mr. J. T. Wright succeeded Mr. H. E. Cookson as an Honorary Member of Council on being elected President of the Staffordshire Iron and Steel Institute, and Mr. F. Bainbridge succeeded Lieut.-Col. Wm. Routledge on being elected President of the Cleveland Institution of Engineers.

Since the close of the year Mr. Henry Bond has expressed his desire to retire from the Council, and has been nominated an Honorary Vice-President, and Mr. E. J. Fox has been elected a Member of Council.

In accordance with Bye-Law 10, the names of the following Vice-Presidents and Members of Council were announced at the Autumn Meeting as being due to retire at the Annual Meeting in 1936 :

Vice-Presidents.—Mr. A. Hutchinson; Mr. John Craig, C.B.E.; Mr. H. Spence Thomas.

Members of Council.—The Rt. Hon. the Earl of Dudley, M.C.; Captain R. S. Hilton; Mr. I. F. L. Elliot; Mr. E. F. Law; Dr. T. Swinden.

No other members having been nominated up to one month previous to the Annual Meeting, the retiring members are presented for re-election.

Honours Conferred on Members.

The Council congratulate members of the Institute on honours and appointments received during the year 1935.

Sir Arthur Balfour was created a baron with the title Lord Riverdale of Sheffield, and knighthoods were bestowed on Mr. W. J. Talbot and Mr. G. A. Mitchell. Mr. W. Pickering was awarded the Order of the Three Stars in the Latvian Independence Day Honours in recognition of his work in promoting Anglo-Latvian economic relations. Sir Peter Rylands was appointed Sheriff of Chester, while Sir William Talbot, Mr. A. J. Grant, and Mr. F. C. Moss became Justices of the Peace for the Borough of Walsall, Sheffield, and the West Riding of Yorkshire, respectively.

Dr. W. H. Hatfield was elected a Fellow of the Royal Society. The Royal Society of Arts awarded the Albert Gold Medal for 1935 to Sir Robert Hadfield, Bart., F.R.S., and a Silver Medal to Mr. S. A. Main. Mr. G. Jeffries was the recipient of the Albert Sauveur Medal of the American Society for Metals, and Professor F. Bacon received the M. C. James Medal of the North East Coast Institution of Engineers and Shipbuilders. On Professor A. M. Portevin the degree of Doctor *honoris causa* was conferred by the École Supèrieure des Mines de Pribram, Czechoslovakia, and Mr. E. A. Atkins received the honorary degree of M.Sc. from the Senate and Council of Liverpool University. The T. Bernard Hall Prize of the Institution of Mechanical Engineers was presented to Dr. H. J. Gough, F.R.S., jointly with Mr. H. V. Pollard, for their paper on the strength of metals under combined alternating stresses. Dr. S. F. Dorey was awarded the Denny Gold Medal by the Institute of Marine Engineers for his paper on "Marine Machinery Defects—Their Causes and Prevention," read before that Institute in December, 1935. Mr. A. B. Winterbottom was awarded a Robert Blair Fellowship in Applied Science and Technology.

Sir William Larke, K.B.E., was elected an Honorary Member, and Mr. J. E. Hurst President, of the Institute of British Foundrymen; Dr. P. D. Merica became a Vice-President of the American Society for Metals, and Mr. P. R. Clarke accepted the Chairmanship of the Rumanian Section of the Institution of Petroleum Technologists. Mr. R. Percival Smith became President of the Rotherham

College of Technology Engineering Society, and Mr. L. Chapman of the Crucible Steel Makers Association; Dr. F. Pišek became President of the Czechoslovak Foundry Technical Association for 1935, and Viscount Falmouth President of the Electrical Development Association. The Earl of Dudley, M.C., is a Vice-President of the Birmingham Chamber of Commerce and President of the British Gas Association, of the National Institute of Industrial Psychology, and, for 1935–36, of the Wolverhampton Literary and Scientific Society.

Presentation to the Former Secretary of the Institute, Mr. G. C. Lloyd.

At the Autumn Meeting of the Institute at Manchester, a presentation was made by members—excluding the Council and French and German members—to Mr. G. C. Lloyd, former Secretary of the Institute, as a sign of their appreciation of the services he had rendered to the Institute as Secretary from January 1909 to July 1933. The presentation was organised by Professor J. H. Andrew, Professor C. O. Bannister, Dr. J. C. Hudson, Mr. Lewis Jones, Mr. C. Peat, Mr. A. Robinson, Mr. C. P. Sandberg, and Mr. T. M. Service, and, at the invitation of the President, was made by Professor J. H. Andrew, who had taken an active part in making the arrangements. A large number of members had subscribed, and Professor Andrew handed on their behalf to Mr. Lloyd a cheque and an inscribed plate to be fastened to a desk which Mr. Lloyd had chosen. (An account of the proceedings will be found in the *Journal of the Iron and Steel Institute*, 1935, No. II., pp. 5–8.)

It should be mentioned that on Mr. Lloyd's retirement in 1933, a presentation had been made to him by the Council and by a number of French members, while German members of the Institute had also combined to make a separate presentation.

Meetings.

The Annual Meeting of the Institute lasted three days. Wednesday, May 1st, 1935, was devoted to the business of the Institute and the discussion of technical papers. Mr. W. R. Lysaght, C.B.E., the retiring President, was in the Chair, and was followed by Sir Harold Carpenter, D.Sc., F.R.S., the incoming President. On Thursday and Friday, May 2nd and 3rd, a Symposium on the Welding of Iron and Steel, organised by the Institute in co-operation with a number of other Technical Societies, was held, and on this a report is given below. The Council wish to express their thanks to the Council of the Institution of Civil Engineers for again permitting the Meetings to be held on their premises.

The Annual Dinner took place at the Connaught Rooms on the evening of Thursday, May 2nd, 1935.

The Autumn Meeting was held at Manchester during the week

beginning September 16th, 1935. Two sessions for the discussion of papers were held on the mornings of September 17th and 18th in the Manchester College of Technology, and during the afternoons visits were paid to works in the district. On Tuesday, September 17th, members were entertained to lunch by the Reception Committee, who were also their hosts at a Banquet and Dance on Wednesday evening. On Wednesday, members were the guests of the Lancashire Steel Corporation; during the afternoon the Ladies, who had made an excursion to Chatsworth House, where a visit was paid by permission of His Grace the Duke of Devonshire, K.G., and to Buxton, were entertained at tea by Mr. and Mrs. John E. James. On Tuesday evening the Lord Mayor and the Corporation of the City of Manchester held a Civic Reception. On Thursday (September 19th) an excursion was made into the Lake District, and visits were paid to works on the Cumberland Coast.

The Council wish to express their sincere thanks to the Iron, Steel, and Engineering Industries of Manchester and the Iron and Steel Industries of the West Coast of Cumberland, to the Reception Committee, its President, the Right Hon. the Earl of Crawford and Balcarres, P.C., K.T., the Chairman, Mr. John E. James, the Hon. Treasurer, Mr. F. J. West, and the Hon. Secretary, Mr. H. D. Lloyd; to Mr. R. Crichton of the Workington Iron and Steel Co., and Major A. Hibbert of Millom & Askam Haematite Iron Co., Ltd., for the delightful hospitality with which the members were received and for all the trouble which they took to make the visit interesting and comfortable.

Symposium on the Welding of Iron and Steel.

As stated above, Thursday and Friday, May 2nd and 3rd, 1935, were entirely devoted to the discussion of papers contributed to the Symposium on the Welding of Iron and Steel, which had been organised in co-operation with fifteen other Societies. The sessions were held in the Grand Hall of the Institution of Civil Engineers, by the courtesy of the Council of that Society, and were attended by about 1000 people. One hundred and fifty papers were submitted; these had been divided into five groups or sub-groups, each of which was presented by a rapporteur. Sir Harold Carpenter, F.R.S. (President of the Institute), was President of the Symposium, and Dr. H. J. Gough, F.R.S., Vice-President; they were supported by the Presidents of the Co-operating Societies, and of these Sir Richard Redmayne, K.C.B. (President of the Institution of Civil Engineers), Colonel A. E. Davidson, D.S.O., A.D.C. (President of the Institution of Mechanical Engineers), and Professor W. M. Thornton, O.B.E. (President of the Institution of Electrical Engineers), also took the Chair during the proceedings. The papers, the discussion and correspondence, and an account of the proceedings were published in two bound volumes, containing together nearly 1600 pages and about 250 plates.

On the eve of the Symposium, Wednesday, May 1st, a Conversazione was held at the Science Museum, South Kensington, by the courtesy of the Director, Col. E. E. B. Mackintosh, D.S.O. In connection with this a Welding Exhibition had been organised with the assistance of companies engaged in the welding industry, and this remained open to the public for a fortnight.

The Council desire to record their thanks to all those who contributed to the success of the Symposium.

RELATIONS WITH OTHER SOCIETIES AND TECHNICAL INSTITUTES.

The Council have maintained and extended friendly relations with other Societies and Technical Institutes, and they hope that the measures which have been initiated may result in the development of closer co-operation with a number of Technical Societies.

An invitation issued to the Council of the Institute of Metals suggesting the initiation of discussions designed to lead to closer co-operation between the two Institutes has been accepted, and conversations will be begun in the near future. As a considerable proportion of members are members of both Institutes, it is hoped that arrangements may be concluded which will be useful to them and also will strengthen the scientific and industrial interests of the Institute.

Resulting from the Symposium on Welding, of which details are given above, the Institute of Welding Engineers was reorganised as the Institute of Welding, Ltd., and the Institute has accepted an invitation to become a Patron.

On the 5th March, 1935, a Joint Meeting, organised by the Institution of Automobile Engineers, was held, and papers on Cold Pressing and Drawing were discussed, in which the Institute, together with the Chemical Engineering Group, the Institute of Fuel, the Institute of Marine Engineers, the Institute of Metals, the Institution of Mechanical Engineers, the Institution of Petroleum Technologists, the Junior Institution of Engineers, the North-East Coast Institution of Engineers, the Royal Aeronautical Society, and the Society of Engineers, took part.

Co-operation with Local Technical Societies.

The co-operation with Local Technical Societies, announced in the last Report of Council, has been continued. During the autumn and winter months the following joint meetings were held with the Societies named :

Saturday, October 12th, 1935 : Newport and District Metallurgical Society.

Place and Time : Newport Technical College, Newport, Mon., at 6.30 P.M.

Chairman : Mr. G. H. Latham, President, Newport and District Metallurgical Society.

Address : " The Heterogeneity of Steel Ingots with Special Relation to Mild Steel," by Dr. W. H. Hatfield, F.R.S.

Monday, October 14th, 1935 : Sheffield Society of Engineers and Metallurgists and Sheffield Metallurgical Association.

Place and Time : The Mappin Hall, The University, Sheffield, at 3 P.M. (first session) and 6.30 P.M. (second session).

Chairman : Mr. James Henderson, Hon. Treasurer of the Iron and Steel Institute.

Papers : "Some Aspects of the Fatigue Properties of Patented Steel Wires.—II.," by Mr. E. T. Gill and Dr. R. Goodacre.

"The Properties of Low-Nickel Steels containing Manganese," by Dr. R. H. Greaves.

"The Behaviour of Mild Steel under Prolonged Stress at 300° C.—Part II.," by Dr. C. H. M. Jenkins.

"Investigation of the Behaviour of Metals under Deformation at High Temperatures.—Part I.," by Dr. C. H. M. Jenkins and Mr. G. A. Mellor.

"Subcutaneous Effects during the Scaling of Steel," by Mr. R. Griffiths.

Friday, October 18th, 1935 : West of Scotland Iron and Steel Institute.

Place and Time : The Societies' Room, Royal Technical College, George Street, Glasgow, at 7.15 P.M.

Chairman : Dr. A. McCance, President of the West of Scotland Iron and Steel Institute.

Paper : "Waste-Heat Boilers in Open-Hearth Practice," presented by Mr. A. F. Webber.

Monday, November 4th, 1935 : Sheffield Society of Engineers and Metallurgists and Sheffield Metallurgical Association.

Place and Time : The Mappin Hall, the University, Sheffield, at 3 P.M. (first session) and 7.30 P.M. (second session).

Chairman : Dr. W. H. Hatfield, F.R.S., Vice-President of the Iron and Steel Institute.

Paper : "Sixth Report on the Heterogeneity of Steel Ingots," presented by Dr. W. H. Hatfield, F.R.S.

Monday, November 18th, 1935 : Sheffield Society of Engineers and Metallurgists and Sheffield Metallurgical Association.

Place and Time : The Mappin Hall, The University, Sheffield, at 7.30 P.M.

Chairman : Mr. A. J. Grant, President of the Sheffield Society of Engineers and Metallurgists.

Paper : "Waste-Heat Boilers in Open-Hearth Practice," presented by Mr. R. Percival Smith and Mr. A. F. Webber.

Tuesday, November 26th, 1935 : Lincolnshire Iron and Steel Institute.

Place and Time : The Modern School, Cole Street, Scunthorpe, at 7.30 P.M.

Chairman : Mr. C. W. D. Townsend, President of the Lincolnshire Iron and Steel Institute.

Paper : "Further Determinations of the External Heat Loss of Blast-Furnaces," by Dr. D. F. Marshall.

Friday, November 29th, 1935 : Staffordshire Iron and Steel Institute.

Place and Time : The James Watt Memorial Institute, Great Charles Street, Birmingham, at 6.30 P.M.

Chairman : Mr. J. T. Wright, President of the Staffordshire Iron and Steel Institute.

Paper : "Sixth Report on the Heterogeneity of Steel Ingots," presented by Dr. C. H. Desch, F.R.S.

Friday, December 6th, 1935: South Wales Engineering Society, South Wales Branch of the Institution of Mechanical Engineers, South Wales Siemens Steel Association, Swansea Technical College Metallurgical Society and Welsh Plate and Sheet Manufacturers' Association.

Place and Time: Royal Metal Exchange, Swansea, at 7.0 P.M.
Chairman: Dr. C. A. Edwards, F.R.S., Principal of the University College of Swansea.
Paper: "Waste-Heat Boilers in Open-Hearth Practice," presented by Dr. M. A. Vernon.

Monday, January 20th, 1936: Cleveland Institution of Engineers.

Place and Time: Cleveland Scientific and Technical Institute, Middlesbrough, at 7.30 P.M.
Chairman: Mr. Frank Bainbridge, President of the Cleveland Institution of Engineers.
Paper: "Waste-Heat Boilers in Open-Hearth Practice," presented by Mr. A. F. Webber.

Tuesday, February 18th, 1936: Lincolnshire Iron and Steel Institute.

Place and Time: The Modern School, Cole Street, Scunthorpe, at 7.30 P.M.
Chairman: Mr. C. W. D. Townsend, President of the Lincolnshire Iron and Steel Institute.
Paper: "Waste-Heat Boilers in Open-Hearth Practice," presented by Mr. A. F. Webber.

The Meetings were well attended and the interest shown in the papers was satisfactory. The Council wish to record their appreciation to the Presidents, Councils, and Secretaries of the Local Societies and to others concerned, as well as to the authors of papers, for their contributions to the success of the meetings.

Co-operation with Foreign Technical Societies.

The Council have offered to extend the maximum age of associate membership of the Iron and Steel Institute, in the case of members of certain foreign Technical Societies of high standing, on lines similar to those agreed last year with Local Technical Institutes in Great Britain. The arrangements have not yet been completed in the case of a number of societies.

The American Institute of Mining and Metallurgical Engineers (A.I.M.E.).

In accordance with reciprocal arrangements recently made with the American Institute of Mining and Metallurgical Engineers, members and associates of the Iron and Steel Institute who are under the age of 33 and who reside in countries other than the United States of America, Canada, and Mexico, are accepted as eligible for election to the newly established class of Junior Foreign Affiliates of the A.I.M.E. The annual subscription for this class is $5, and no initiation fees are payable. These reduced rates are applicable for six years after enrolment, provided that the individual

does not in the meantime attain the age of 33, after which the annual subscription is $15. In comparison with the normal subscription and fees, these reduced rates represent a very generous concession.

Junior Foreign Affiliates are entitled to most of the other privileges of membership of the A.I.M.E., and particularly to the receipt, free of charge, of the following publications: (1) Mining and Metallurgy (monthly); (2) Metals Technology (monthly for 8 months in the year); and (3) the Annual Transactions (Iron and Steel Division). They may also purchase other publications of the A.I.M.E. at the greatly reduced rates prevailing for members of the A.I.M.E.

Forms of application for becoming a Junior Foreign Affiliate of the A.I.M.E. can be obtained on application to the Secretary of the Iron and Steel Institute.

The Council have arranged for the age limit for associates who are members of the A.I.M.E. to be extended to 33 years of age.

L'Association des Ingenieurs Sortis de l'École de Liége.

This old-established Belgian Society has accepted an offer according to which the age limit for associate membership of the Iron and Steel Institute is extended to 30 years of age in the case of its members.

Jernkontoret.

By arrangement with Jernkontoret, members of the Iron and Steel Institute are privileged to obtain copies of Jernkontorets Annaler (published in twelve monthly parts) at a yearly subscription of Swedish Kr. 10 (postage extra) instead of the standard price of Swedish Kr. 18. Members wishing to avail themselves of this privilege should inform the Secretary of the Iron and Steel Institute.

The Council have arranged for the age limit for associates who are members of the staffs of companies members of Jernkontoret to be extended to 30 years of age.

Papers.

Twenty-three papers were contributed to the Proceedings of the Institute during the year. Of these, ten were presented at the Annual Meeting and thirteen at the Autumn Meeting. The Third Report of the Corrosion Committee, the Sixth Report on the Heterogeneity of Steel Ingots and a Report on Waste-Heat Boilers in Open-Hearth Practice were published as separate volumes in the Special Report Series of the Institute. The following is a complete list:

"Third Report of the Corrosion Committee."—Being a Report by a Joint Committee of the Iron and Steel Institute and the British Iron and Steel Federation to the Iron and Steel Industrial Research Council.

"Sixth Report on the Heterogeneity of Steel Ingots."—Being a Report by a Joint Committee of the Iron and Steel Institute and the British Iron and Steel Federation to the Iron and Steel Industrial Research Council.

"Waste-Heat Boilers in Open-Hearth Practice."—Second Report of the Open-Hearth Committee, being a Committee of the Iron and Steel Industrial Research Council.

ANDREW, J. H., and G. T. RICHARDSON.—"An Investigation of Spring Steels."

CASWELL, J. SELWYN.—"The Deflection of the Rolls in Plate, Sheet, and Strip Mills."

FELL, E. W.—"The Piobert Effect in Iron and Soft Steel."

GILL, E. T., and R. GOODACRE.—"Some Aspects of the Fatigue Properties of Patented Steel Wires. II.—Note on the Effect of Low-Temperature Heat Treatment."

GOODRICH, W. E.—"The Penetration of Molten White Metals into Stressed Steels."

GREAVES, R. H.—"The Properties of Some Low-Nickel Steels containing Manganese."

GRIFFITHS, R.—"Subcutaneous Effects during the Scaling of Steel."

HANKINS, G. A., and H. R. MILLS.—"The Resistance of Spring Steels to Repeated Impact Stresses."

HERBERT, A. M., and F. C. THOMPSON.—"The Use of the Hele-Shaw Apparatus in the Investigation of the Flow of Metals."

HOARE, W. E., and B. CHALMERS.—"Examination of the Surface of Tinplate by an Optical Method."

JENKINS, C. H. M.—"The Behaviour of Mild Steel under Prolonged Stress at 300° C. Part II.—Experiments on Concentrated Stress in Notched and Drilled Specimens."

JENKINS, C. H. M., and G. A. MELLOR.—"Investigation of the Behaviour of Metals under Deformation at High Temperatures. Part I.—Structural Changes in Mild Steel and Commercial Irons during Creep."

MARSHALL, D. F.—"Further Determinations of the External Heat Loss of Blast-Furnaces."

MATUSCHKA, B.—"Non-Metallic Inclusions in Ferro-Alloys."

MAURER, E., and W. BISCHOF.—"The Distribution of Phosphorus between Metal and Slag in the Basic Process of Steel Manufacture."

PORTEVIN, A. M., and R. CASTRO.—"Morphology of the Inclusions in Siderurgical Products."

ROONEY, T. E., and A. G. STAPLETON.—"The Iodine Method for the Determination of Oxides in Steel."

SYKES, C., and H. EVANS.—"Transformations in Iron-Aluminium Alloys."

WHITE, J., R. GRAHAM, and R. HAY.—"An Investigation into the Oxidising Power of Basic Slags."

WHITELEY, J. H.—"An Effect of Oxygen and Sulphur on Iron in Scaling."

The following two communications were also printed in the Journal:

DEARDEN, W. H.—"A Note on Reproducible Sulphur Prints."

JIMENO, E., and I. GRIFOLL.—"Electro-Chemical Interpretation of 'Cleaning.'"

Volume XXIV. of the Carnegie Scholarship Memoirs was published in 1935, and contained the following Reports:

CUTHBERTSON, J. W.—"The Load-Deflection Fatigue Test. A Critical Investigation of its Application to Steels."

KLEINEFENN, W.—"Notched-Bar Toughness of Fusion Welds at Low and High Temperatures."

MADDOCKS, W. R.—"The Ternary System FeO–MnO–SiO_2."
MEARS, R. B.—"Effect of Composition on the Corrosion Probability of Iron and Steel."
WENTRUP, H.—"The Desulphurisation of Pig Iron and the General Laws Governing the Desulphurisation of Iron."

PUBLICATIONS.

Two volumes of the Journal, a volume of Carnegie Scholarship Memoirs, and three Special Reports—the Third Report of the Corrosion Committee, the Sixth Report on the Heterogeneity of Steel Ingots, and a Report on Waste-Heat Boilers in Open-Hearth Practice (Second Report of the Open-Hearth Committee of the Iron and Steel Industrial Research Council)—were published during the year.

The monthly bulletin "Iron, Steel and Industrial Fuel" was also issued throughout the year. This publication was originally designed to serve as a guide to important articles of interest to the iron and steel manufacturer published in the technical press both in this country and abroad. In view of the wide use made of it, however, it has been decided to widen its scope and to include, besides abstracts of articles of a practical nature, others of interest to the physical metallurgist; in fact, the new Bulletin will be found to represent a monthly advance issue of the contents of the Abstract Section of the Journal, in which the abstracts will be on permanent record. The enlarged publication, the first copy of which appeared in January, 1936, is issued under the title "Bulletin of the Iron and Steel Institute."

ANDREW CARNEGIE RESEARCH SCHOLARSHIPS.

Grants were made by the Council in 1935, to the following candidates:

M. ALEXANDER (University College, Swansea).—£100 for the further study of the influence of gases on the position of blow-holes in steel ingots.
W. HOOK (Newcastle-on-Tyne).—£100 for a study of the pyrolysis of organic compounds with a view to determining the factors which favour graphite formation.
T. RAINE (Sheffield University).—£100 for an investigation of the determination of oxygen in steel.
G. T. RICHARDSON (University of Leeds).—£100 for an investigation of the influence of furnace atmospheres on steels.
J. B. VICKERS (Sheffield University).—£100 for an investigation of the determination of oxygen in steel.
G. BOOTH (Refractories Department, Sheffield University).—£100 for an investigation on basic refractories, with particular reference to their use in linings of induction furnaces.
R. GOODACRE and E. T. GILL (Messrs. Bruntons Research Laboratory, Musselburgh).—£100 for an investigation of some aspects of the fatigue properties of cold-drawn wires.
R. MITSCHE (Eisenhütteninstitut der Montanistischen Hochschule, Leoben). £50 for the continuation of the research into the flotation of non-metallic inclusions and the application of the fluorescence microscope in the field of the non-metallic inclusions.

H. NIPPER (Institute of Foundry Practice, Aachen).—£50 for a research on recrystallisation tests on ferritic cast irons.

W. W. O. RUFF (Laboratories of the Bergische Stahl-Industrie, Remscheid).—£100 for a research on the running qualities of cast iron and steel under standardised pouring conditions.

A. A. TIMMINS (The British Cast Iron Research Association, Birmingham).—£50 for a research on the formation and decomposition of pearlite in cast iron.

ANDREW CARNEGIE GOLD MEDAL.

The Andrew Carnegie Gold Medal for the year 1935 was awarded to Dr. D. F. Marshall, of Sheffield, for his paper entitled "Further Determinations of the External Heat Loss of Blast-Furnaces," which was published in the No. I. *Journal of the Iron and Steel Institute* for 1935 (p. 59).

WILLIAMS PRIZE.

For the year 1935, no award of the Williams Prize was made.

LIBRARY.

The position of the Library as the main source of reference in the iron and steel industry has been well maintained, and increasing use was made of the book collection. To this important additions have been made during the past year; a number of volumes have been presented, and the Council take this opportunity to extend thanks, on behalf of the Members, to the donors.

The publication of the new "Bulletin of the Iron and Steel Institute," containing abstracts of all the important technical literature, is designed to fit in with the continued extension of the Library, and it has led to an increased demand by the members for the loan of original articles.

The majority of the articles abstracted in the Bulletin are filed in the Library and are available for loan. Photographic copies of articles can be supplied under certain conditions, and this service should prove very valuable to overseas members.

In addition to the Institute's Library, the valuable collection of scientific works included in the Science Library, South Kensington, is available for loan, by kind permission of the Director of the Science Library.

A list of the additions made to the Library is issued quarterly, and copies will be sent to Members on request.

The work of the Information Department has increased greatly during the year, and assistance has been rendered to Members and industrial companies both in this country and abroad. A special feature of the work of this Department has been the compilation of bibliographies for the various Technical Committees of the Institute.

Iron and Steel Industrial Research Council.

The active participation of the Iron and Steel Institute in the Iron and Steel Industrial Research Council has been maintained, and by means of this the Institute has taken an increasingly active part in controlling the joint research activities of the Industry and in encouraging co-operative research.

The Council wish to express their satisfaction at the financial arrangements which have been concluded—details of which are shown in the Accounts—and to record their appreciation of the assistance they have received from the Department of Scientific and Industrial Research, the British Iron and Steel Federation and the Iron and Steel Industrial Research Council.

Technical Committees.

The following Committees and Sub-Committees are Joint Committees of the Institute and the Iron and Steel Industrial Research Council engaged on co-operative research :

Alloy Steels Research Committee; Chairman, Dr. W. H. Hatfield, F.R.S. Established June, 1934. Meetings held during 1935, six.

Sub-Committee A, Thermal Treatment; Chairman, Mr. P. B. Henshaw. Established January, 1936.

Corrosion Committee; Chairman, Dr. W. H. Hatfield, F.R.S. Established July, 1928. Meetings held during 1935, eight.

Laboratory (Corrosion) Research Sub-Committee; Chairman, Dr. U. R. Evans. Established June, 1930. Meetings held during 1935, nil.

Protective Coatings Sub-Committee; Chairman, Mr. T. M. Herbert. Established January, 1936.

Heterogeneity of Steel Ingots Committee; Chairman, Dr. W. H. Hatfield, F.R.S. Established May, 1924. Meetings held during 1935, eight.

Liquid Steel Temperatures Sub-Committee; Chairman, Mr. E. W. Elcock. Established March, 1929. Meeting held during 1935, one.

Ingot Moulds Sub-Committee (joint with the Open-Hearth Committee of the Iron and Steel Industrial Research Council); Chairman, Mr. R. H. Myers. Established November, 1934. Meetings held during 1935, four.

Steel Castings Research Committee; Chairman, Mr. W. J. Dawson. Established November, 1934. Meetings held during 1935, six.

Moulding Materials Sub-Committee; Chairman, Mr. W. J. Rees. Established March, 1936.

The work of the Corrosion, Heterogeneity of Steel Ingots, and Steel Castings Research Committees, and of the various Sub-Committees, has been actively continued; the Third Report of the Corrosion Committee and the Sixth Report of the Heterogeneity of Steel Ingots Committee were presented at the Annual and Autumn Meetings of the Institute, respectively. Summaries of the work

of these two Committees, from their establishment till the 31st December, 1935, have been prepared by the Chairman, Dr. W. H. Hatfield, F.R.S., and issued as Special Reports Nos. 11 and 12, respectively.

During the year the Alloy Steels Research Committee was established and an important programme of research undertaken.

The Council wish to express their appreciation to the Iron and Steel Industrial Research Council and the British Iron and Steel Federation for the support which they have given to these research Committees, to the Lords of the Admiralty, the British Steelwork Association and Lloyd's Register of Shipping for their financial support to the Corrosion Committee; to a number of associations and companies for grants to the Alloy Steels Research Committee, the Liquid Steel Temperature Sub-Committee and the Steel Castings Research Committee; and to all those associations, companies and individuals who have given facilities for experiment or contributed in time and materials to the work of all the Committees, without whose valuable assistance the researches could not be carried out.

The Worshipful Company of Blacksmiths.

In accordance with the understanding with the Wardens of the Worshipful Company of Blacksmiths, applications for nomination for admission to the Company were considered, and Lieut.-Col. Wm. Routledge, of Middlesbrough, and Lieut.-Col. M. A. Wolff, O.B.E., of Birmingham, were recommended by the Council for admission to the Company.

Appointment of Representatives.

The following is a list of the Institute's representatives on various governing bodies and committees for the year 1935; it has been brought up to date to April 1, 1936:

Association of Scientific and Technical Institutions, Council: Sir Robert Hadfield, Bt., F.R.S.

British Association, Fuel Economy Committee: Sir Robert Hadfield, Bt., F.R.S.

British Cast Iron Research Association: Professor T. Turner.

British Corporation Register of Shipping and Aircraft, Committee of Management and Technical Committee: Dr. A. McCance.

British Electrical and Allied Industries Research Association, Sub-Committee J/E, Joint Committee, Steels for High Temperatures: Dr. W. H. Hatfield, F.R.S., Dr. T. Swinden.

British Refractories Research Association, Council: Sir Robert Hadfield, Bt., F.R.S., Mr. F. W. Harbord, C.B.E.

British Standards Institution,
Chemical Engineering Divisional Council: Mr. E. F. Law.
Engineering Divisional Council E/-: Dr. W. H. Hatfield, F.R.S., Dr. T. Swinden, Mr. J. Bird.
Solid Fuel Industry Committee: Mr. A. F. Webber.
Standardisation of Coal Burning Appliances: Mr. A. F. Webber.
Sub-Committee M/33/7, Protective Glasses for Welders and Industrial Purposes: Dr. C. H. Desch, F.R.S.
Technical Committee B/16, Breeze and Clinker Slabs: Mr. F. W. Harbord, C.B.E.
Technical Committee EL/28, Fans: Mr. A. F. Webber.
Iron and Steel Industry Committee IS/-: Dr. T. Swinden.
Technical Committee IS/1, Co-ordination of Iron and Steel Specifications: Dr. T. Swinden.
Technical Committee IS/6, Steel Castings: Dr. R. H. Greaves.
Technical Committee IS/7, Alloy Steels: Dr. R. H. Greaves.
Technical Committee IS/8, Creep Properties: Dr. W. H. Hatfield, F.R.S.
Technical Committee ME/22, Marking and Colouring of Foundrymen's Patterns: Mr. F. W. Lewis.
Technical Committee ME/25, Testing of Thin Metal Sheet and Strip: Dr. T. Swinden.
Technical Committee ME/32, Engineering Symbols and Abbreviations: Dr. T. Swinden.
Technical Committee ME/35, Cast Iron: Mr. H. B. Toy.
Public Works Industry Committee PW/-: Mr. J. Henderson.
Technical Committee PW/34, Portland Blast-Furnace Cement: Mr. F. W. Harbord, C.B.E.
Technical Committee SF/1, Nomenclature and Definitions: Mr. A. F. Webber.
Technical Committee SF/2, Underfeed Screw Type Stokers: Mr. A. F. Webber.
Technical Committee SF/4, Furnaces, Ovens, and Kilns: Mr. A. F. Webber.
Technical Committee SH/5, Ships Materials: Mr. E. J. George.

City and Guilds of London Institute,
Advisory Committee on Metallurgy: Sir Harold Carpenter, F.R.S.
Examiner in Iron and Steel Manufacture: Professor W. H. Merrett.

Constantine College, Advisory Committee: Mr. E. W. Jackson.

Department of Scientific and Industrial Research, Grey and Malleable Cast Iron Research Committee: Professor T. Turner.

Empire Council of Mining and Metallurgical Institutions: Mr. F. W. Harbord, C.B.E., Mr. K. Headlam-Morley.

HONG KONG UNIVERSITY, Home Committee: Sir Robert Hadfield, Bt., F.R.S.
INSTITUTE OF FUEL, Council: Mr. F. W. Harbord, C.B.E.
INSTITUTE OF WELDING, LTD., Council: Mr. K. Headlam-Morley.
IMPERIAL COLLEGE OF SCIENCE AND TECHNOLOGY, Board of Governors: Mr. B. Talbot.
IRON AND STEEL INDUSTRIAL RESEARCH COUNCIL: Mr. F. W. Harbord, C.B.E., Dr. W. H. Hatfield, F.R.S., Mr. K. Headlam-Morley.
LIVERPOOL UNIVERSITY, Court of Governors: Sir W. Peter Rylands.
LLOYD'S REGISTER OF SHIPPING, Technical Committee: Mr. John Craig, C.B.E., Mr. J. S. Hollings.
MECHANISATION BOARD (Late Mechanical Warfare Board) (Army Council): Mr. F. W. Harbord, C.B.E.
METALLIFEROUS MINING AND QUARRYING INDUSTRIES, ADVISORY COMMITTEE: Professor H. Louis, M.A., D.Sc.
NATIONAL PHYSICAL LABORATORY,
General Board: Dr. A. McCance, Dr. W. H. Hatfield, F.R.S.
Alloys of Iron Research Committee: Mr. F. W. Harbord, C.B.E.
RAMSAY MEMORIAL LABORATORY, Advisory Committee: Mr. F. W. Harbord, C.B.E.
ROYAL SCHOOL OF MINES, Advisory Board: Mr. F. W. Harbord, C.B.E.
ROYAL SOCIETY, General Board for Administering Government Grants for Scientific Investigations: The President.
SCHOOL OF METALLIFEROUS MINING (CORNWALL), Board of Governors: Professor H. Louis, M.A., D.Sc.
SCIENCE MUSEUM, Advisory Council: Sir Harold Carpenter, F.R.S.
SHEFFIELD UNIVERSITY, Court of Governors: Sir Robert Hadfield, Bt., F.R.S.

[The Statement of Accounts for 1935 will be found in the following pages.]

THE IRON AND

BALANCE SHEET,

LIABILITIES.	£ s. d.	£ s. d.
Sundry Creditors :—		
Office Rent, &c.	204 15 8	
Journal Printing, Vol. I., 1935	614 15 9	
Telephone Calls	9 12 10	
Office Furniture	13 3 3	
Library Books	1 0 7	
Printing and Stationery	86 2 1	
Sundries	10 9 2	
Bulletin	17 2 0	
Corrosion Committee	40 19 0	
Ingot Committee	3 10 0	
Open Hearth Committee	1 10 0	
Carnegie Research Fund *re* I.S.I.R.C.	208 6 8	
Autumn Meeting	3 8 2	
Postages	14 14 4	
		1,229 9 6
Subscriptions in Advance :—		
Home Members	12 12 0	
Foreign Members	42 3 5	
Associates	1 11 6	
		56 6 11
Entrance Fees in advance		2 2 0
Journal Sales :—		
Amount in advance, 1936	31 4 2	
Received on account, Vol. II., 1935 ...	150 9 5	
		181 13 7
Suspense Accounts :—		
Special Appeal Contributions held in Suspense	1,000 0 0	
Reserve for 10-year Index	50 0 0	
Entrance Fees	201 5 0	
		1,251 5 0
Welding Symposium :—		
Estimated amounts due for Printing Proceedings, Binding, &c.	1,915 6 9	
Less Contributions receivable and Sales of Publications	749 19 1	
		1,165 7 8
Research Committees Contributions collected :—		
Corrosion Research Committee	400 0 0	
Alloy Steels Research Committee ...	1,215 5 0	
Steel Castings Research Committee ...	197 7 0	
	1,812 12 0	
Less Grants due	1,000 0 0	
		812 12 0
Life Composition Fund :—		
As at 1st January, 1935		3,110 2 2
Iron and Steel Institute :—		
Capital and Reserve Account :—		
Capital as per last Balance Sheet ...	23,873 12 4	
Add Accumulated Excess of Income over Expenditure as at 1st January, 1935 ... ... 901 19 10		
Excess of Income over Expenditure for the year... 27 8 4		
	929 8 2	
		24,803 0 6
		£32,611 19 4

STEEL INSTITUTE.

31ST DECEMBER, 1935.

ASSETS.

	£ s. d.	£ s. d.
Sundry Debtors :—		
Subscriptions in arrear		Not valued.
Journal Sales	330 5 4	
Do. 10-year Index	13 4	
Amount due from Carnegie Research Fund	151 16 6	
Telephone Deposit	1 0 0	
		483 15 2
Payments in Advance :—		
Insurance	3 18 6	
Library Books	21 19 6	
Staff Superannuation Fund	110 10 0	
Sundries	4 10 0	
Rent, Insurance, &c., Corrosion Committee	12 7 5	
		153 5 5
Stock of Journals		Not valued.
Office Furniture and Library		Not valued.
Investments at cost per Schedule :—		
General Fund		23,873 12 4
(The Market value of these Securities at 31st December, 1935, was £28,212 3*s.* 4*d.*)		
Cash at Bank and in Hand :—		
Current Account	352 2 1	
Secretary's Account	13 13 9	
Deposit Account	3,350 0 0	
Deposit Banque de Plovdiv, Bulgaria ...	5 5 0	
Cash at Office	25 15 2	
		3,746 16 0
Welding Symposium :—		
Excess of Expenditure over Income to date as per separate Accounts ...		1,244 8 3
Life Composition Fund :—		
Investments at cost per Schedule ...	3,081 15 2	
Cash at Bank	28 7 0	
		3,110 2 2
(The market value of these Securities at 31st December, 1935, was £3,324 4*s.* 9*d.*)		
		£32,611 19 4

INCOME AND EXPENDITURE ACCOUNT

INCOME.

	£ s. d.	£ s. d.
To Entrance Fees	201 5 0	
Less Transferred to Reserve Account...	201 5 0	— — —
Annual Subscriptions :—		
Members, Home—Current	3,241 7 0	
Arrears	206 17 0	
		3,448 4 0
Members, Foreign—Current	1,556 2 5	
Arrears	88 4 9	
		1,644 7 2
Associates		60 18 0
Sales of Publications :—		
Journals, &c.	1,267 11 10	
Bulletin	24 5 7	
		1,291 17 5
„ Interest on Investments (*less* Tax) :—		
General Fund	910 4 2	
Life Composition Fund	101 19 4	
Bessemer Medal Fund	12 8 0	
		1,024 11 6
„ Interest on Deposit		11 16 1
„ Sundry Receipts		4 18 11
„ Income Tax Recovered, 1934–1935 :—		
General Fund	75 4 10	
Life Composition Fund	15 0 2	
Bessemer Medal Fund	3 12 0	
		93 17 0
„ I.S.I.R.C. :—		
Grant for Bulletin	500 0 0	
Grant for Secretarial Services	500 0 0	
Grant by Carnegie Research Fund ...	416 13 4	
	1,416 13 4	
Less Amount to be repaid to Carnegie Research Fund in respect of their contribution towards Expenditure	208 6 8	
		1,208 6 8
, Balance, being Excess of Expenditure over Income carried down		1,932 11 8
		£10,721 8 5
To Special Appeal Fund :—		
Contributions received during 1935 ...		£2,010 0 0
		£2,010 0 0

FOR THE YEAR ENDED 31ST DECEMBER, 1935.

EXPENDITURE.

	£ s. d.	£ s. d.
By Salaries (including Pensions and Overtime)		4,501 5 0
„ National Insurance		32 8 8
„ Staff Superannuation Fund		197 0 6
„ Office Rent, Cleaning, &c.		933 0 0
„ Library Books, Binding, &c.		175 5 11
„ Office Furniture		89 13 9
„ Annual Meeting		125 8 9
„ Autumn Meeting		349 17 4
„ Publishing Expenses :—		
Journal, Printing and Paper	1,349 7 2	
Abstracts	90 10 6	
Postage	142 8 0	
Advance Copies, Printing	174 7 7	
Postage	35 0 0	
Bulletin, Printing	163 12 0	
Postage	11 5 0	
List of Members	109 3 9	
		2,075 14 0
„ Stationery and Printing		322 7 10
„ Postage and Receipt Stamps		119 16 6
„ Travelling and Entertainment Expenses		65 11 11
„ Insurance		6 17 1
„ Telephone Rental and Calls		59 16 5
„ Auditor's Fees		31 10 0
„ Bessemer Medal		20 17 6
„ Compassionate Allowance		20 0 0
„ Office Disbursements and Sundry Expenses		138 5 3
„ Grants :—		
British Electrical and Allied Industries Research Association	50 0 0	
British Refractories Research Association	25 0 0	
British Standards Institution	50 0 0	
International Association for Testing Materials	5 0 0	
Joint Meeting on Cold Pressing ...	6 4 0	
Institute of Physics	6 0 0	
		142 4 0
„ I.S.I.R.C. :—		
Heterogeneity of Steel Ingots Committee	710 16 1	
Corrosion Committee	385 16 4	
Alloy Steels Research Committee ...	52 10 0	
Steel Castings Research Committee ...	12 14 10	
Ingot Moulds Sub-Committee ...	3 10 0	
Open-Hearth Committee	99 0 9	
Graphite Formation	50 0 0	
		1,314 8 0
		£10,721 8 5
By Balance brought down		£1,932 11 8
„ Transfer Reserve Account, 10-year Index		50 0 0
„ Excess of Income over Expenditure carried to Balance Sheet		27 8 4
		£2,010 0 0

WELDING SYMPOSIUM.

INCOME AND EXPENDITURE ACCOUNT FOR PERIOD ENDED 31ST DECEMBER, 1935.

INCOME.	£ s. d.	£ s. d.
Contributions	830 0 0	
Sales	2,118 11 4	
Exhibition—Contributions	76 0 0	
Balance, being Excess of Expenditure over Income ...	1,244 8 3	
NOTE.—Stock of Volumes unsold at 20th February, 1936 —Not valued		
	£4,268 19 7	

EXPENDITURE.	£ s. d.	£ s. d.
Printing and Binding Proceedings	3,433 13 0	
Printing Circulars	266 2 2	
		3,699 15 2
Translations		97 14 6
Conversazione		185 1 0
Reporting		53 5 10
Interpreter		21 0 0
Postage		150 0 0
Symposium Expenses		33 15 0
Miscellaneous		28 8 1
		£4,268 19 7

ANDREW CARNEGIE RESEARCH FUND.

BALANCE SHEET, 31ST DECEMBER, 1935.

LIABILITIES.	£ s. d	£ s. d	£ s. d.
Sundry Creditors :—			
Grants	375 0 0		
Amount due to General Fund	151 16 6		
Auditor's Fee	10 10 0		
Tibor Ver's A/c	24 15 7		
		562 2 1	
Amount of Original Fund ($100,000) ...	21,241 5 6		
Add Amounts since Capitalised	2,912 9 6		
	24,153 15 0		
Add Surplus Income as at 1st January, 1935 ...	1,544 12 8		
Deduct Excess of Expenditure over Income for the year	40 12 0		
	1,504 0 8		
		25,657 15 8	
		£26,219 17 9	

ASSETS.	£ s. d.	£ s. d.	£ s. d.
Investments at Cost per Schedule			25,355 16 10
(The Market value of these Investments at 31st December, 1935, was £32,630 8s. 9*d*.)			
Cash at Bank :—			
On Current Account	258 9 3		
On Deposit Account	350 0 0		
		608 9 3	
Payments in advance		47 5 0	
Sundry Debtors :—			
General Fund Research Committees ...		208 6 8	
		£26,219 17 9	

ANDREW CARNEGIE RESEARCH FUND.

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDED 31ST DECEMBER, 1935.

INCOME.	£	s.	d.
To Interest on Investments	995	9	10
,, Income Tax recovered, 1934–1935	183	1	0
,, Interest on Deposit		19	8
,, Balance, being Excess of Expenditure over Income carried to Balance Sheet	40	12	0
	£1,220	2	6

EXPENDITURE.	£	s.	d.	£	s.	d.
By Scholarship Grants	512	10	0			
,, Scholarship Grants—I.S.I.R.C. 416 13 4						
Less Refund by General Fund of the Iron and Steel Institute 208 6 8						
	208	6	8			
				720	16	8
,, Printing Memoirs, Vol. 23				382	15	10
,, Salaries				104	0	0
,, Sundries				2	0	0
,, Audit Fee				10	10	0
				£1,220	2	6

WILLIAMS PRIZE FUND.

BALANCE SHEET, 31ST DECEMBER, 1935.

LIABILITIES.	£ s. d.	£ s. d.	ASSETS.	£ s. d.	£ s. d.
Capital Account representing the Market Value of £3,000 3½% Conversion Loan at 21st September, 1926, when Fund was inaugurated	2,220 0 0		£3,000 3½% Conversion Loan (at Cost) ...	2,220 0 0	
Income and Expenditure Account :—			Cash at Bank	276 15 1	
Balance as at 1st January, 1935,	158 12 7				2,496 15 1
Add Excess of Income over Expenditure for the year to 31st December, 1935 ...	118 2 6		(The Market Value of this Security at 31st December, 1935, was £3,232 10s.)		
	276 15 1				
		2,496 15 1			
		£2,496 15 1			£2,496 15 1

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDED 31ST DECEMBER, 1935.

	£ s. d.		£ s. d.
To Interest on 3½% Conversion Stock	105 0 0	By Excess of Income over Expenditure carried to Balance Sheet	118 2 9
,, Income Tax recovered, 1934–1935	13 2 6		
	£118 2 6		£118 2 6

IRON AND STEEL INSTITUTE.

SCHEDULE OF INVESTMENTS AT 31ST DECEMBER, 1935.

(Showing Nominal Values, Cost Values, and present Market Values.)

Nominal Value.	Nature of Security.	Market Value. 31/12/1935.	Cost Value.
£ s. d.		£ s. d.	£ s. d.
	GENERAL FUND OF THE INSTITUTE.		
2,197 7 0	3½% War Stock	2,329 3 9	2,161 0 8
324 7 4	3½% Conversion Loan	349 10 0	231 1 0
447 0 0	Southern Railway 4% Debenture Stock...	500 12 9	449 2 4
1,872 0 0	London and North Eastern Railway 4% 2nd Guaranteed Stock	1,722 5 0	2,149 13 3
2,241 0 0	London and North Eastern Railway 4% 1st Guaranteed Stock	2,229 15 11	2,431 14 5
1,500 0 0	Buenos Ayres Great Southern Railway 4% Debenture Stock...	1,117 10 0	1,594 12 9
1,000 0 0	Calcutta Bonds 4%, 1939	1,030 0 0	982 10 0
800 0 0	Bombay Bonds 4%, 1939	824 0 0	809 0 0
2,954 1 0	4% Consolidated Stock	3,426 13 11	3,175 18 1
437 0 0	London and North Eastern Railway 3% Debenture Stock	358 6 9	376 12 5
12,242 19 3	4% Funding Loan, 1960–1990	14,324 5 3	9,512 7 5
		£28,212 3 4	£23,873 12 4
	LIFE COMPOSITION FUND.		
386 6 0	3½% Conversion Loan	416 4 9	304 10 0
1,330 0 0	London and North Eastern Railway 3% Irredeemable Debenture Stock	1,090 12 0	1,254 17 6
594 0 0	London Passenger Transport Board 4½% "A" Stock	727 13 0	638 6 1
130 4 8	3½% Conversion Loan	140 6 6	137 11 0
143 6 0	3½% War Loan	151 17 11	146 10 7
681 13 0	4% Funding Loan	797 10 7	600 0 0
		£3,324 4 9	£3,081 15 2

Nominal Value.	Nature of Security.	Market Value. 31/12/1935.	Cost Value.
£ s. d.		£ s. d.	£ s. d.
ANDREW CARNEGIE RESEARCH FUND.			
6,897 14 11	3½% War Stock	7,311 12 2	6,895 16 6
2,693 12 0	3½% Conversion Loan	2,902 7 0	2,006 19 0
227 9 4	3% Local Loans	219 10 1	202 10 0
2,300 0 0	India 3½% Stock	2,231 0 0	1,600 2 9
2,560 4 0	India 3% Stock	2,201 15 5	1,525 3 3
2,250 0 0	N.E. Electric Supply Co. 3½% Consolidated 1st Mortgage Debenture Stock	2,325 10 4	2,261 10 0
1,500 0 0	G.W. Railway 4% Debenture Stock	1,703 5 0	1,204 5 3
2,000 0 0	L.M.S. Railway 4% Debenture Stock	2,160 0 0	1,693 0 6
1,312 0 0	L.N.E. Railway 4% 1st Guaranteed Stock	1,305 8 9	880 11 11
5,000 0 0	L.N.E. Railway 4% Debenture Stock	5,350 0 0	3,540 8 5
6,000 0 0	L.N.E. Railway 3% Debenture Stock	4,920 0 0	3,545 9 3
		£32,630 8 9	£25,355 16 10
WILLIAMS PRIZE FUND.			
3,000 0 0	3½% Conversion Loan	£3,232 10 0	£2,220 0 0
BESSEMER MEDAL FUND.			
	Trustees: Sir Harold Carpenter, Lord Airedale, and Francis Samuelson, Esq.		
400 0 0	London, Midland and Scottish Railway 4% Debenture Stock	— — —	— — —

(*Signed*) JAMES HENDERSON,
Hon. Treasurer.

(*Signed*) K. HEADLAM-MORLEY,
Secretary.

I have examined the foregoing Balance Sheets and Income and Expenditure Accounts with the Books and Vouchers of the Institute and certify them to be correct. I have also verified the Balances at the Bankers and the Securities for the Investments shown above.

23 QUEEN VICTORIA STREET,
LONDON, E.C. 4.
7th March, 1936.

(*Signed*) W. B. KEEN,
Chartered Accountant.

SOME CONSIDERATIONS INFLUENCING PLANT FACILITIES FOR STRIP-SHEET PRODUCTION UNDER BRITISH CONDITIONS.[1]

By GEO. A. V. RUSSELL, Wh.Ex., Assoc.M.Inst.C.E.
(Birmingham).

Summary.

The increasing number of wide-strip mills in the United States of America has focused attention upon the commercial possibilities attaching to the introduction of the production methods made feasible by such plants in Great Britain. A consideration of the differences between British and American conditions leads the author to advance the view that smaller productive units are desirable in this country, provided that capital costs can be reduced proportionately, and that substantially the same direct costs are attainable. The importance of standing charges in the economics of these installations is emphasised and the principal factors influencing capital outlay are analysed. Certain conclusions are then reached concerning the features which should characterise a plant to meet British requirements. In exemplification, three projects have been elaborated for wide-strip mill plants of different capacities and product ranges.

The revolution in methods of sheet production which commenced in the United States some 13 years ago with the resuscitation of the backed-up mill and its employment for both the hot- and cold-reduction of wide strip, has now acquired such momentum as to threaten with extinction the pre-existing techniques as serious contributors to the total volume of sheet and light plate production. This has happened despite the particularly unfavourable trading conditions obtaining over the past five years. The change has been in part brought about by a significant alteration in the character of an increasingly important section of the sheet market (both as to tonnage and value) that finds its outlet in the automobile, furniture, and similar industries. These consuming interests have become more exacting in their standards of quality—metallurgical, dimensional, and superficial—and the trend has been towards demanding an improved product in larger unit sizes. This attitude on the part of an important body of consumers has made it easier for the new methods with their inherently superior quality characteristic to advance in the face of general dullness in the steel trade. Again, the important realisable savings in direct costs of production, particularly in labour, power, and scrap loss, made a strong appeal to a harassed industry confronted with a predominantly buyers'

[1] Received February 29, 1936.

market, which was reflected in the keenness of the struggle to share in the business available. There is now apparent a danger that sight may be lost of the fact that such low direct costs are only translatable into correspondingly low overall or "financial" costs if the very high standing charges introduced with the new type of installation can be sufficiently diluted by adequate tonnage. The acceleration in the rate of changeover to the new methods which became manifest in 1934 is also attributable to the fact that it is the policy of some leading interests to cater more extensively for the flat-rolled products market than previously. Again, it is probable that it has been also partially occasioned by the desire to stimulate the capital goods industries.

The situation developing in the United States will soon be full of interest. By the end of the present year it is anticipated that there will be at least twenty-one wide-strip mills, capable of rolling maximum widths of from 32 to 84 in., in operation, and in addition two continuous light plate mills. Many of these plants will have complementary cold-reduction facilities. Their aggregate productive capacity (exclusive of the plate mills) may be conservatively assessed at 8,500,000 tons per annum. Unless consumption is substantially greater than has been the case over the last five years, the only outlet for the new installations will be at the expense of the pre-existing manufacturing facilities for the products in question, namely, the sheet mills, jobbing plate mills, tinplate mills, skelp mills, medium strip mills, and their attendant preparatory rolling plants. In many instances the denuded mills will be owned by the same concern as the new wide-strip plants, and they will not always have been fully amortised. In other cases, the business for the new plants will have to be obtained in competition with firms operating conventional facilities. Some valuable lessons will no doubt be derivable from observations made when all the new capacity at present under construction or in contemplation is ready for operation.

In Great Britain these developments have naturally attracted much attention. As was the case in America, where the installation at Rome paved the way for their introduction in the steel industry, so the non-ferrous industry here has been the first to exploit them on a comprehensive scale. Now, however, it is understood that several installations are about to be made by leading steel interests. Having the advantage of some experience in strip-sheet production, it occurred to the author that it might be useful to consider in broad outline the application of the new methods to British conditions. This will, he hopes, serve as a basis for a discussion which will help to establish the most suitable ways of applying the signal technical achievements that have been made in the United States under the radically different economic conditions obtaining in Great Britain, so that their introduction may prove a commercial success, not only in good times, but also when trade declines. It

is proposed to confine attention to new projects for rolling wide material for the various branches of the sheet and strip trades, as the author has elsewhere given an indication of the economic benefits accruing from grafting the new practices on to existing plants producing the narrower and often thinner products required in the tinplate industry.[1]

Doubtless the most important difference between American and British conditions lies in the size of the economic producing unit. Owing to a much smaller total demand, coupled with a somewhat greater degree of diversity in its character, real scope for a typical large American continuous mill, having an annual capacity exceeding 400,000 tons, can scarcely be said to exist. While one or two such installations could no doubt be operated, and even earn a profit when the demand was heavy, their influence on the general economics of the country would be harmful, owing to the excessive concentration of activities engendered, and the long-term financial results would be likely to be disappointing. What is needed, in the author's opinion, to meet British requirements is a plant with a capacity of not more than half the above figure, with the same range and product flexibility, but capable of operating at a direct cost approximating closely to that of the large American installations, and representing a smaller investment for plant and buildings, at least in the same proportion. While it will be apparent that these desiderata are not readily met, the author feels that a good deal towards their realisation is possible, and, again, he hopes that the ensuing discussion will assist in the solution of the technical problems involved.

As the standing charges—interest and depreciation—are the most important constituents making up the cost of production on wide-strip mill plants, it is desirable to examine those factors which influence their capital cost, as then a clearer picture is likely to emerge of the features which must be embodied in any installation where capital cost is to be kept at a minimum.[2] These

[1] "The manufacture of Tinplate: Application of Recently Developed Rolling Techniques." *Iron and Coal Trades Review*, 1935, vol. 130, Jan. 11, pp. 86–87.

[2] The investment represented by a modern American 80-in. continuous mill is stated to be about $10,000,000, or something over £2,000,000. As construction costs in the United States are considerably higher than in Britain, such an installation would, perhaps, cost £1,700,000 here. Conservative finance would dictate a fairly high rate of depreciation for such an installation, and in the author's view this should not be less than 8%. Insurance, management, and other charges would not exceed 1½%, whilst the rate of interest on the capital involved should not be taken at less than 4% in view of the long-term nature of the investment. This makes a total rate of 13½% or about £230,000 per annum. To this, something may have to be added to cover charges on any unamortised manufacturing assets which will be rendered obsolete or redundant. The rated capacity of a wide-strip mill of this size is considered to be 600,000 tons per annum, but it is unlikely that more than 500,000 tons could be sold in any one financial year. Thus it will be seen that the standing charges amount to over 9*s*. per ton under favourable conditions, and will approach 17*s*. per ton should production decline 45%. In comparison, the

may be conveniently resolved under the following main and sub-headings:

A.—Product Conditions—Primary.

(1) Minimum thickness of stock to be rolled.
(2) Maximum width for the thickness given in *A* (1).
(3) Maximum width to be rolled at some thickness greater than that given in *A* (1).
(4) Limits of accuracy in longitudinal gauge imposed on the most difficult product embraced by the rolling programme, *i.e.*, that defined by *A* (2).
(5) Maximum weight per foot of width of the strip defined by *A* (2).
(6) Maximum weight per foot of width of the strip defined by *A* (3).
(7) Range of composition of steels rolled.

B. Product Conditions—Secondary.

(1) Disposal facilities required to put the range of products into suitable form for (*a*) further processing, *e.g.*, skin-rolling, annealing, pickling, pickling and cold-reduction, flattening, &c., (*b*) immediate disposal in the as-rolled condition.
(2) Storage space required to accommodate finished products for (*a*) further processing, (*b*) direct disposal.

C.—Operating Conditions.

(1) Available slab supplies (*a*) maximum weight, (*b*) maximum width, (*c*) thickness, (*d*) average quality in respect of mechanical and metallurgical defects.
(2) Operating hours per week available for rolling the designed capacity of the plant.

D.—Design Characteristics.

(1) Standards of mechanical and electrical design adopted.
(2) Layout of the mill train proper, as affecting the provisions for driving the various roll stands.
(3) Layout of the plant as affecting (*a*) the floor area required, (*b*) building features and crane servicing for production and maintenance purposes.

It will be necessary when considering these factors to refer to American practice when evidence is required in support of the views

average productive labour cost, from the reception of slabs into the slab yard (including slab conditioning) to coiling or piling the product, lies between 2*s.* 6*d.* and 4*s.* per ton of finished product, according to the plant facilities and wage rates. Again, the total power consumption for main and auxiliary drives will not average more than 50 kWh. per ton, giving a power cost in the region of 1*s.* 6*d.* per ton.

advanced. Where the author has been unable to furnish such data from personal observation, he has drawn principally upon the able series of papers recently published by the Association of Iron and Steel Electrical Engineers and the American Iron and Steel Institute.[1]

A.—Product Conditions—Primary.—The minimum thickness which must be rolled in conjunction with the maximum width of stock desired of this thickness are perhaps the most important factors governing the design of a plant, but scarcely less important is the maximum width (at a thickness greater than the minimum), as this obviously controls the size of the individual roll stands. The question of minimum gauge is bound up with a consideration of what lines should be finish-rolled in the hot-strip mill and what products should be rolled to final gauge by cold-reduction, or alternatively by cutting up wide-strip mill stock and subsequently processing by ordinary hot sheet-mill methods. There is undoubtedly a considerable market for 18- and 20-gauge (0·049-in. and 0·035-in.) sheets of ordinary quality for which a hot-rolled strip stock would be suitable, but it will be generally admitted that below 16 gauge (0·065 in.) the width of strip that can be hot-rolled and the productivity of the mill decline rather rapidly. Some of the newest American installations are claimed to roll stock down to 18 gauge in widths up to 54 in., and with the Steckel hot mill 12 gauge (0·104 in.) is, the author understands, considered to be the optimum thickness.[2] It would appear that the ability to roll down to 16 gauge is an essential attribute of a modern wide-strip mill plant, while if 18 gauge can also be reached, some advantage is realisable when producing narrower hot-rolled material for slit strip, &c., or extra thin stock for cold reduction.

The greatest width of stock procurable in the thinnest gauge from a particular plant will depend upon the arrangement of the roll stands, their powering, and their speed ranges. A straight-line tandem-continuous medium-width mill with high maximum delivery speed will be capable of delivering its thinnest gauge

[1] Special acknowledgment is due to the following authors:

C. L. McGranahan, "Flat Rolling of Steel, Factors Influencing its Production." Association of Iron and Steel Electrical Engineers, Sept., 1935: *Iron and Steel Engineer*, 1935, vol. 12, Dec., pp. 1–11.

R. W. Davies, "76-in. Hot Strip Mill, Inland Steel Co." Association of Iron and Steel Electrical Engineers, Sept., 1934: *Iron and Steel Engineer*, 1934, vol. 11, Dec., pp. 486–490.

S. Badlam, "The Evolution of the Wide Strip Mill." *Yearbook of the American Iron and Steel Institute*, 1927, pp. 343–413.

S. Badlam, "Developments in Rolling Flat Steel Products during 1935." Association of Iron and Steel Electrical Engineers, Sept., 1935: *Iron and Steel Engineer*, 1935, vol. 12, Dec., pp. 40–50.

[2] *See* the remarks on p. 214 of E. R. Mort's valuable paper on "The Manufacture of Full-Finished Steel Sheets." *Journal of the Iron and Steel Institute*, 1934, No. I., pp. 187–251.

in its maximum width,[1] whereas a wide mill incorporating a cross-rolling stand could not be expected to roll its thinnest gauges in much over 80% of its maximum width.[2] With a Steckel plant, no fundamental obstacle prevents the production of the full width down to the thinnest gauges, but actually the decrease in productivity with diminishing gauge is more rapid than in tandem-continuous mills, and this—as has just been said—tends to set a commercial limit.

The maximum width for which a wide-strip mill should be designed is no longer a question of technical practicability, as plants can now be built for any reasonable width likely to be called for. The markets to be supplied, their character and magnitude, coupled with the capital available for the proposed installation, become therefore the determinants. It will be generally agreed that a 60-in. mill caters well for the bulk of what may be termed the ordinary sheet business, and can also enter the strip field. If the light plate and heavy skelp markets are also to be tapped, a mill not less than 78 in. wide becomes virtually essential. At the other end of the scale a 40-in. mill admirably meets the requirements of the tinplate industry, and the owners of such a mill would be enabled to quote for a substantial business in narrow sheets and also in wide strip and narrower slit strip. When deciding upon the range of a projected plant it is useful to recollect that although the capital cost of the mill machinery proper and electrical equipment for wide-strip mill installations of the conventional tandem-continuous type tends to increase at a rate nearly proportional to the maximum width rolled, the other expenditures do not grow so rapidly. As these latter elements of cost amount to not less than 40% of the total investment the choice of a greater width than that necessitated by the programme envisaged for the immediate future may prove a reasonable long-term investment.

Although the cross-sectional accuracy of the product delivered by the wide-strip mills is superior to that of any previous product, and is well up to the requirements of the most exacting consumers, the variation in longitudinal gauge can be a serious problem, especially in plants of the straight tandem-continuous type, where an appreciable difference in time elapses between the passage of the front and back ends of a length of strip through the finishing stand. In one of the latest installations an air-spraying system has been fitted over the rear part of the connecting table between the roughing and finishing trains to counter this variation. The jets are manipulated progressively as the piece advances towards the finishing train, with the result, it is claimed, that a total tem-

[1] An example of such a plant is provided by the 43-in. mill at the MacDonald works of the Carnegie-Illinois Steel Corporation, which is stated to be capable of rolling down to 18 gauge in widths up to 37 in.

[2] The Inland Steel Company's 76-in. mill, and the Ford Motor Company's 56-in. mill may be taken as examples. In the former 18 gauge stock can be rolled in widths up to 54 in. and in the latter up to 48 in. wide.

perature variation of the order of 60° C. in a strip as it leaves the roughing train is equalised. It will be apparent that this problem is aggravated with heavier pieces unless the rolling speeds are proportionately increased at the expense of increased horse-power for the motors of the various roll stands.

The tendency manifest in the more recent American wide-strip mill plants to increase the weight per foot of width of the strip rolled has resulted in higher plant costs by—

(*a*) increasing the hearth areas of the slab heating furnaces.

(*b*) widening the spacing of the tandem roughing stands and also the length of the intermediate connecting table between the tandem and continuous sections of the mill.

(*c*) increasing the horse power of the motors driving the stands of the finishing train, owing to the necessity of greater rolling speeds.[1]

Mr. Badlam recently pointed out that the coil weight of the earlier mills, which averaged about 1000 lb. per foot of width, has increased to 2000 lb. on some of the newer 80-in. mills and is as much as 3600 lb. in the case of the 43-in. mill at the MacDonald Works of the Carnegie-Illinois Steel Corporation. The author is inclined to question whether the advantages of these extremely long strips counterbalance the increased standing charges on the extra investment requirement for the facilities for their production. It should be remembered that flats are never wanted in enormous lengths, and the proportion of flat stock rolled in most wide-strip mills is considerable. Heavy coils, while desirable for increasing the efficiency of the subsequent cold-rolling operations, particularly on reversing mills, can be built-up from smaller coils at reasonable expense.

The range of composition of the products rolled will obviously have an influence on the layout and facilities provided, especially on the heating equipment, and on the number of roll stands. If much medium- and high-carbon strip is produced, the provision of coiling equipment may be scarcely justified.

[1] The subjoined comparison of the powering of the finishing trains of two wide-strip mills may be of interest in this connection. The Weirton Mill commenced rolling in 1928, whilst the Ford Mill was put into operation in 1935.

54-in. Mill. Weirton Steel Co.			*56-in. Mill. Ford Motor Co.*		
Stand.	Rolls.	H.p.	Stand.	Rolls.	H.p.
1st	16 × 40 × 54 in.	2,000	1st	21 × 46 × 56 in.	3,000
2nd	,,	2,000	2nd	,,	3,000
3rd	,,	2,500	3rd	,,	3,000
4th	,,	2,500	4th	,,	3,000
5th	,,	2,500	5th	,,	2,500
		11,500			14,500

B.—Product Conditions—Secondary.—On leaving the finishing stand of a wide-strip mill the product may be shipped directly after cooling, either in flat lengths or coils. Usually, however, it will undergo further processing to meet the demands of various trades. In either case, the disposal facilities must keep in step with the mill, avoid superficial damage to the stock, and preserve intact the hot-rolled surface. Narrower mills would be adequately equipped if provided with a couple of coilers and a set of flying shears, pinch rolls, and a stacking device for piles of flat material. In some recent installations these arrangements are reinforced by the provision of a broadside transfer, cooling bed, and a run-out table from the latter leading in one direction through a leveller to a flying shear with stacking equipment, and in the other to a stationary shear and piling stand. When light plates and heavy skelp are included in the rolling programme the disposal facilities require further augmentation by greater cooling-bed area, and probably a second run-out table for the heavy products which have traversed the whole width of the cooling bed. The receiving, cooling, and cutting-up equipment of modern wide-strip mills requires much building space, and its influence on capital costs is important. Judicious expenditure at this end of a plant, however, gives a good return by increasing the possible range of production and also by assuring unhampered operations at the mill proper.

The storage accommodation for finished products depends entirely upon local conditions and whether the plant rolls chiefly for direct disposal or whether the product is worked up further at the same site, as when cold-reduction facilities are put down in conjunction with a hot mill.

C.—Operating Conditions.—The nature of the slab supply exerts an important influence upon the design of a wide-strip mill plant, and thus upon its cost. The type of blooming facilities available and the open-hearth practice will determine within narrow limits both the maximum width of slabs that can be offered to the strip mill and their maximum weight. Where a universal slabbing mill exists, the same restriction upon the width of slab will not hold as when an ordinary blooming mill is employed. With the last-named, slabs over 42 in. wide are not readily rolled, even if the top roll of the mill permits pieces of greater width being edged. If, therefore, a strip mill is to cater for widths in excess of this figure, a cross-rolling stand must be incorporated to spread the slab the requisite amount. The employment of a slabbing mill will increase the possible width of slab to about 60 in. From the standpoint of blooming-mill operations, the slab thickness should not be under 4 in. unless a decrease in productivity can be accepted. Thick slabs are also likely to improve the quality of the strip-mill product, owing to the greater opportunity they offer for the elimination of ingot surface and blooming defects by the combination of furnace treatment and rolling. Unfortunately, the influence of

increasing slab thickness is prejudicial to the strip mill, from the aspects both of plant layout and of operation. Thin slab stock enables the total number of passes to be reduced and the draftings eased, with resulting savings in the cost of mill stands and drives, and afterwards in roll wear and power consumption. A compromise must be sought between the conflicting requirements for efficient blooming and strip rolling. Owing to the much greater cost of the latter plant, some sacrifice of blooming mill output is, perhaps, not an unduly high price to pay for reasonably thin slabs carefully rolled.

Apart from their cross-sectional dimensions, the unit weight of slabs should be chosen as a definite sub-multiple of the size of ingots produced by the steel plant after making allowance for crops. Should it be a question of installing a new blooming mill in conjunction with a hot-strip mill of the relatively moderate capacity envisaged in this paper, there are strong arguments for keeping to a relatively small size of slab ingot—say, below 5 tons. Not only will there result appreciable savings in the installation costs of the blooming mill and its drive, but the yield from such ingots is likely to be somewhat higher than from heavier ones.

The factor of operating hours has only been included for completeness, it being obvious that with an installation of the magnitude of a wide-strip mill it will be the aim of its sponsors to run the plant continuously. In fact, if the prospects of being able to do this are at all uncertain, then simpler and cheaper types and plant and other methods should be adopted, since the standing charges of a wide-strip mill are too onerous unless it is so operated.

D.—Design Characteristics.—It is well known that, apart from questions of adequate strength, the general standard of design of a mill plant influences its cost to an appreciable extent. Modern wide-strip mills, in view of the magnitude of the basic conceptions underlying them, their dependence—for successful functioning—on a high degree of mechanisation, and the employment of many exacting and refined mechanical appliances, offer the greatest scope for ingenuity and engineering ability. That full advantage has been taken of these opportunities by those responsible for the design of the latest American plants, there can be no doubt. From the purely technical point of view these installations deserve the highest praise as crowning achievements of the rolling-mill building art. When planning a plant of substantially smaller productive capacity, however, the designer must not allow his ideals of mechanical and electrical perfection quite such free scope as in these American installations, but must continually and drastically apply to them the brake of economic justification, for only thus can the investment cost be kept down to a point where the standing charges thereon will be low enough to be supportable. This is not intended to imply that only a crude and somewhat shoddy job should be made of such plants, but rather that they should be so conceived, both as to general layout and detailed design, that the

utmost simplicity is achieved and every piece of equipment is utilised to the maximum extent; furthermore, it should be borne in mind that, in general, mechanical plant is cheaper than electrical. An interesting development which should cheapen four-high mill stands is the successful substitution of flood-lubricated plain bearings for roller bearings on the backing rolls of large units.[1]

With the typical tandem-continuous layout characterising all the modern American wide-strip mill plants, the individual driving of each roll stand becomes almost inevitable. This results in an admittedly high investment in main-drive motors, many of which machines operate with but a poor factor of utilisation. In seeking ways and means of reducing plant costs this point should not be lost sight of, and the layout of the mill train proper should be developed with a view to cutting down the number of main roll motors, accepting thereby a departure from the straight-line continuous disposition, and the adoption of the cross-country layout.

Building costs may amount to upwards of 15% of the total cost of a large wide-strip mill plant, and an even higher percentage of an installation for narrower products. A good deal of the total building area is determined by external circumstances, such as the conditions of slab supply and amount of finished material it will be necessary to accommodate to suit the trading conditions under which the plant will operate. The remainder, however, is directly influenced by the general layout of the plant itself, and here again opportunities for effecting savings in construction costs occur, by the adoption of a compact layout, keeping the general arrangement of buildings as simple as possible, and utilising fully all the crane facilities that are necessary for operations and maintenance.

With these considerations in mind, it is now easier to discern the lines along which a wide-strip mill plant, with a productivity adapted to British conditions, should be designed. In the first place, as many lines of product should be catered for as can be reasonably considered to lie within its field. The highest degree of flexibility both in product and range that can be embodied will afford the best insurance for continuous operation at a remunerative level during its economic life.[2] The plant will thus be, to a con-

[1] This type of bearing was introduced by Mr. C. E. Davies and Messrs. W. H. A. Robertson & Co., Ltd., in Great Britain some eight years ago (Patent No. 297,623) and has been applied to numerous cold-strip and -sheet mills with considerable success. Lately the Morgan Construction Co. in the United States have brought out their so-called Morgoil bearing, which is a constructional variant of the pioneer design, and has met with a favourable reception both here and in the United States. Two of the most recent American 79-in. hot-strip mills are provided with backing-roll bearings of a similar type.

[2] The author in a previous paper drew attention to the influence of flexibility in assuring a higher level of year-in year-out operation as compared with plants having a more restricted range of production. See *Journal of the Iron and Steel Institute*, 1934, No. II., p. 25.

siderable extent, protected from the effects of vagaries in demand arising from changes in fashion affecting any of the major outlets for its production. To this end the mill should not be restricted to too narrow a maximum width. Bearing in mind the increasing cost of the mill equipment as the width goes up, it would seem that a good compromise might be effected by the selection of a 60-in. length of barrel for the finishing train. This width is adequate to roll readily sheet stock and light skelp up to 54 in. in width, in addition to narrower material for the strip and narrow sheet trades. It will be desirable to include light plates up to $\frac{3}{4}$ in. thick and 6 ft. wide if these can be rolled whenever the rolls of the finishing train are being changed. With this addition, the full range of products turned out by a modern American 80-in. mill will be within the capabilities of the plant. Such a mill should be able to deliver its widest strip in thicknesses down to 16 gauge at least, and it should be proportioned to roll narrower material, say, up to 42 in., in as thin as 18 gauge. The length of strip which can be rolled need not be excessively long, for the reasons already discussed, but coils weighing up to 1000 lb. per ft. of width may be reasonably demanded. The disposal facilities would have to be adapted to handle the full range of products. There would be required flattening, cooling, and shearing equipment for wide heavy lines, and coilers and cutting-up, piling and slitting facilities for sheet and strip. The mill should be adapted to work in conjunction with a normal reversing blooming mill rolling comparatively small slab ingots, say, of 4 tons net weight, and these should not need to be slabbed down below 4 in. thick. While the plant as a whole should be very robustly proportioned, the greatest simplicity of mechanical and electrical design must be insisted upon to keep the cost low, and the layout must be compact to economise in building space.

To afford some concrete evidence of the practicability of designing wide-strip mill plants in accordance with the general indications which have just been adumbrated, the author proposes to outline three projects for such plants that he has investigated. While these schemes have been developed to cater for different conditions, they are all designed to enable narrow plates, either universal or sheared, up to $\frac{3}{4}$ in. in thickness to be rolled, in addition to wide strip. The plates, in all cases, are rolled at the preparatory stands, so that this production can be undertaken while the finishing train is undergoing roll-changing. Another distinguishing feature shared by the three schemes is the provision of reheating facilities for use at an intermediate stage of the reduction. This valuable feature was, the author believes, introduced into strip-rolling technique by Broemel, who conceived the brilliant idea of coiler-equipped reheating furnaces on either side of a reversing stand. Steckel further developed this scheme by placing such furnaces

above and clear of the roller tables and improving their construction. By this means a higher degree of control over the temperature conditions is secured during rolling, and owing to the maintenance of the heat in the strip, long lengths can be produced in thin gauges and with small end-to-end gauge differences. It is also interesting to recall that the early continuous-sheet rolling installation at the Ashland Works of the American Rolling Mill Co. made extensive use of the principle of intermediate reheating. The operating cost of such reheating furnaces must be offset against their advantages, but this is not a serious item if well-designed and adequately insulated equipment is employed.

First Project.—When the maximum width of strip demanded does not exceed 42 in. the need for slab cross-rolling facilities disappears, and the resulting strip-mill plant is thereby simplified. The scheme illustrated in Fig. 1 (Plate I.) affords an example of this. The project has a designed productivity of about 175,000 tons per annum, made up principally of strip, both in coil and flat form. Facilities are afforded for rolling universal plates up to 60 in. in width on the reversing breaking-down stand. The slabs for such work would require widening at this stand, which would impose a limit upon the weight of plate produceable in this width, but such a restriction would not exist in respect of universal plates as wide as, or narrower than, the slabs available.

The plant comprises a 36 × 72 in. reversing universal roughing stand, followed by a four-stand continuous-strip finishing train, each stand being of the four-high type and mounting 18×44×48 in. rolls. The general layout thus follows that of the Butler plant of the American Rolling Mill Co., but as it incorporates provisions for wash-heating stock at the roughing stand and also for the disposal of plates, &c., rolled thereon at times when the finishing train is standing, the flexibility of the plant is greater, and it is, in consequence, better adapted to British conditions.

The wash-heating furnace is of the walking-beam type, with separate charging and drawing mechanisms. The heating period allowed is not less than 10 min., but depends upon the slab weight. With the layout suggested there is no interruption of normal rolling when wash-heating is being done, since when the desired thickness is reached, instead of proceeding further with a particular slab, it is transferred to the charging side of the furnace, while a wash-heated piece is withdrawn from the delivery side and immediately rolled down to the thickness required for the finishing mill. It is not intended that wash-heating should be practised for all work, but only for extra thin strip and for orders where specially rigid requirements as to physical properties have to be met.

The disposal arrangements call for no special comment, as they follow accepted modern practice for wide-strip and universal plate

TABLE I.—*First Project—Principal Characteristics.*

Productive Capacity.

Productive capacity per annum	175,000 tons.
Working weeks per annum	50
Average weekly output	3,500 tons.
Number of working shifts per week	15
Working hours per shift	8
Working hours per week	120
Average hourly output	29·2 tons.
Designed maximum hourly output to allow for delays, breakdowns, and roll changing	35 tons.

Products.

Universal plates up to 60 in. wide and $\frac{3}{4}$ in. thick.
Strip in coils or flats up to 42 in. wide and down to 16 gauge; narrower strip up to 36 in. wide down to 18 gauge.
Bar-plate, sheet mill "breakdowns" and skelp within the foregoing dimensions.

Roll Stands and Drives.

Ref. Letter.	Type and Designation.	Roll Dimensions. In.	Speed. R.p.m.	Driving Motor. H.p.	Driving Motor. R.p.m.
A.	Reversing universal breaking-down.	36 × 72	±140	6,000 *	±140
B.	Universal four-high 1st continuous.	18 and 44 × 48	55–110	2,750	250–500
C.	Four-high 2nd continuous.	18 and 44 × 48	72·5–145	2,750	250–500
D.	Four-high 3rd continuous.	18 and 44 × 48	90–180	2,750	250–500
E.	Four-high 4th continuous.	18 and 44 × 48	107·5–215	2,750	250–500

Capital Cost.—Summary.

	£
(*a*) Mill plant, furnaces, and auxiliary productive equipment	201,100
(*b*) Electrical plant, including main and auxiliary drives, cables, transformers, sub-station equipment	125,920
(*c*) General services; steam, water, gas, compressed air, hydraulic power and spray water	21,650
(*d*) Cranes and other materials—handling equipment	16,350
(*e*) Buildings, foundations, sewers, service tunnels, rail connections, and other civil engineering work	132,900
(*f*) Miscellaneous items, roll conditioning equipment, offices, welfare provisions, &c.	15,650
Total	£513,570

Standing Charges.

13½% on total cost = £69,330
= 7*s.* 11*d.* per ton based on rated capacity.

* Ilgner reversing equipment, mill motor 1,500,000 lb.ft. maximum torque capacity from zero to 70 r.p.m. Ilgner set driven by a 3,500 h.p. induction motor.

mills. The leading data pertaining to the technical and economic features of this scheme are given in Table I.[1]

Second Project.—The present scheme is submitted as an illustration of the type of installation which the author visualises as being well suited to the production of the greatest range of wide-strip mill products under British conditions. At the same time, it involves no very important departure from conventional methods except for the introduction of an optional wash-heating at an intermediate stage. This example is a plant having a capacity of approximately 200,000 tons of finished products per annum. The range of width for plates is up to 74 in., and for strip up to 54 in. The former are produced by the roughing units of the assembly, and can thus be rolled whilst the finishing train is undergoing roll-changing. Narrower plates can be also rolled through the latter train and passed to the normal disposal arrangements. As the layout in Fig. 2 (Plate II.) shows, the mill is arranged on the "cross-country" principle. There are six stands of rolls. The first is a very heavy three-high universal stand which serves for cross-rolling slabs to width and also for the early reducing passes. In addition to lifting tables this unit is equipped with turntables on either side of the rolls, centring guides, and "sticking" devices for ensuring positive entry with heavy drafts. The next stand is an intermediate three-high universal mill with deflecting tables. The drive for the small middle roll is of the semi-positive type. The foregoing stands are driven at appropriate speeds by a common induction motor through a special reduction gear unit. Stock may either pass directly from the first stand to the second over a high-speed broadside transfer, or be routed through a wash-heating furnace of similar design to that previously discussed. Behind the intermediate stand lies a four-stand continuous finishing train of four-high units.

The disposal arrangements resemble those provided for the first project, but a supplementary coiler has been added near the delivery end of the finishing train to receive metal which it is desired to coil as hot as possible to obtain a self-annealing effect. The main battery of coilers is located at a sufficient distance from the mill to permit of pieces running clear before wrapping up. The essential data for this plant are summarised in Table II.

[1] In the estimate of capital cost given in this Table, as also for those given in Tables II. and III., the following assumptions have been made: Land is available in the form of a good level site and the nature of the ground is such that ordinary foundations without piling will be adequate to carry the heavy equipment and building stanchion bases. Three-phase, 50-cycle electrical energy at 11,000 V. is brought up to the plant, and the electrical equipment to be provided commences with the main incoming switch-gear. An independent gas producer plant has been allowed for. A steam supply is available and has merely to be brought in. No spares are included, it being generally considered that these should be charged to maintenance account.

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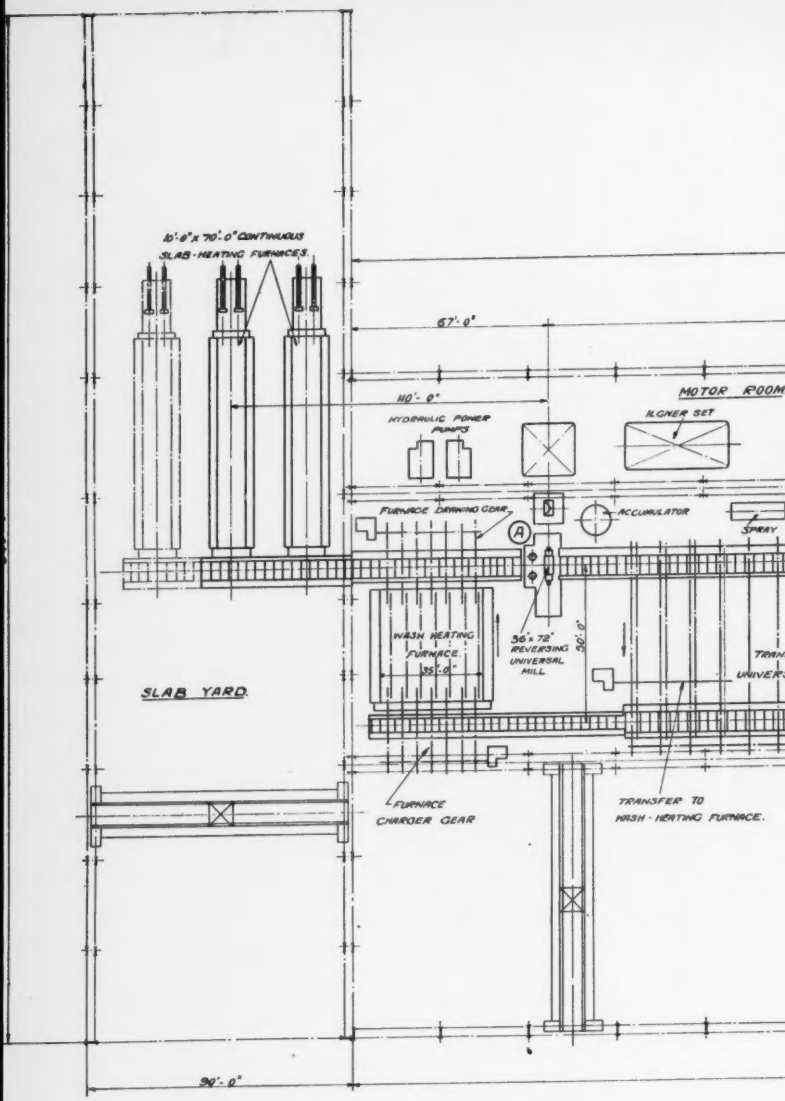

10'-0" x 70'-0" CONTINUOUS SLAB-HEATING FURNACES
67'-0"
110'-0"
MOTOR ROOM
HYDRAULIC POWER PUMPS
ILGNER SET
FURNACE DRAWING GEAR
A
ACCUMULATOR
SPRAY
WASH HEATING FURNACE. 135'-0"
36" x 72" REVERSING UNIVERSAL MILL
50'-0"
SLAB YARD.
FURNACE CHARGER GEAR
TRANSFER TO WASH-HEATING FURNACE.
94'-0"

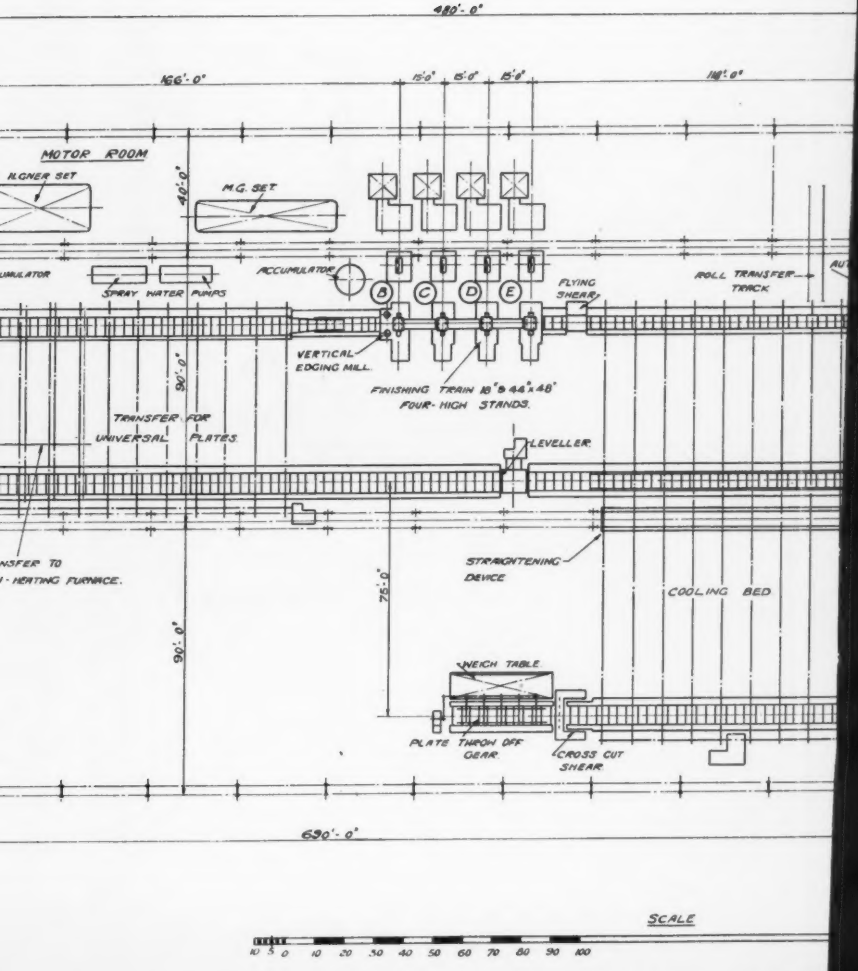
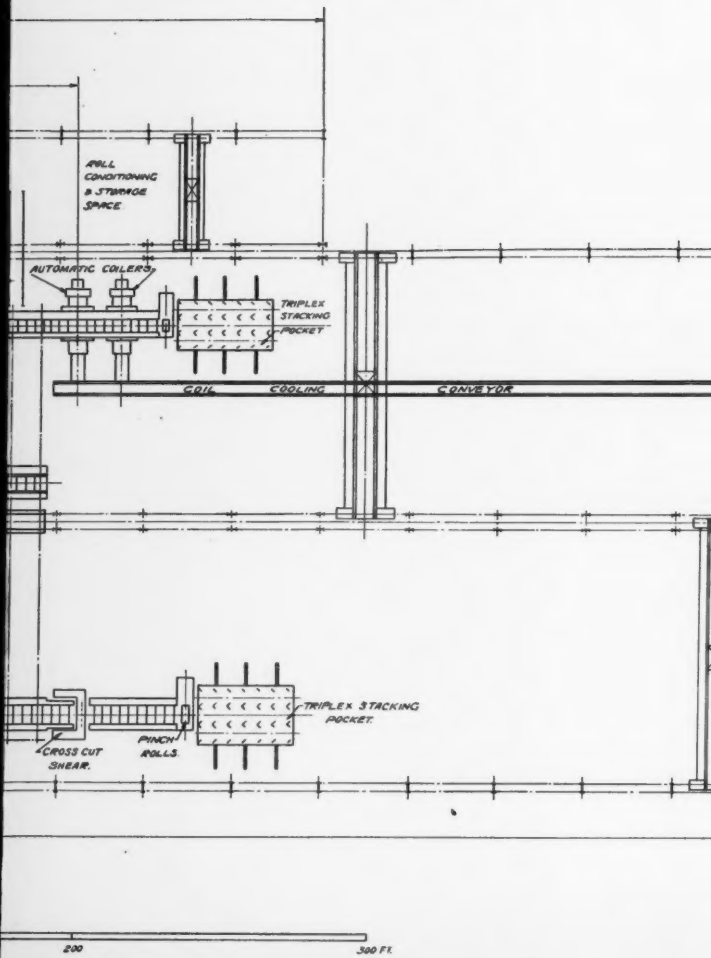


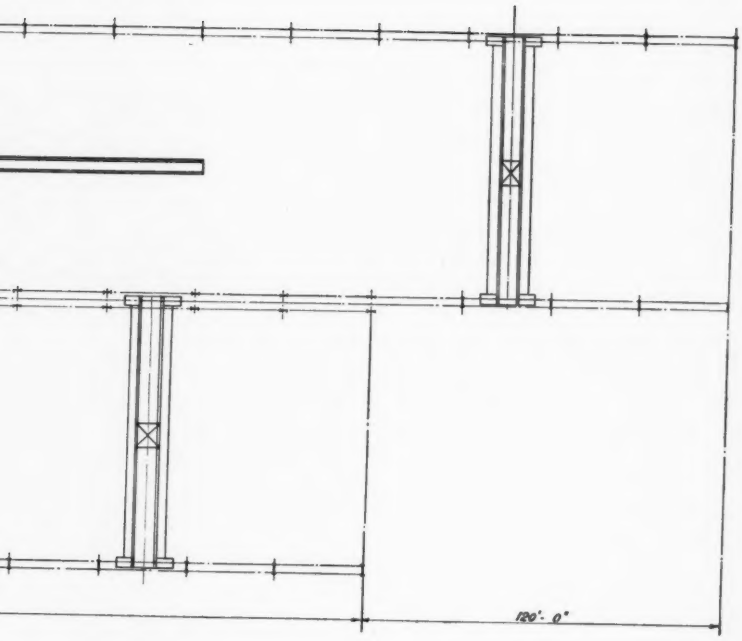
FIG. 1.—Semi-Continuous Wide-Stri



trip Mill Plant.

PLATE I.

59072 15



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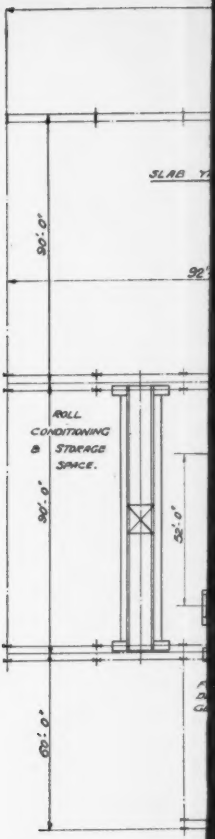
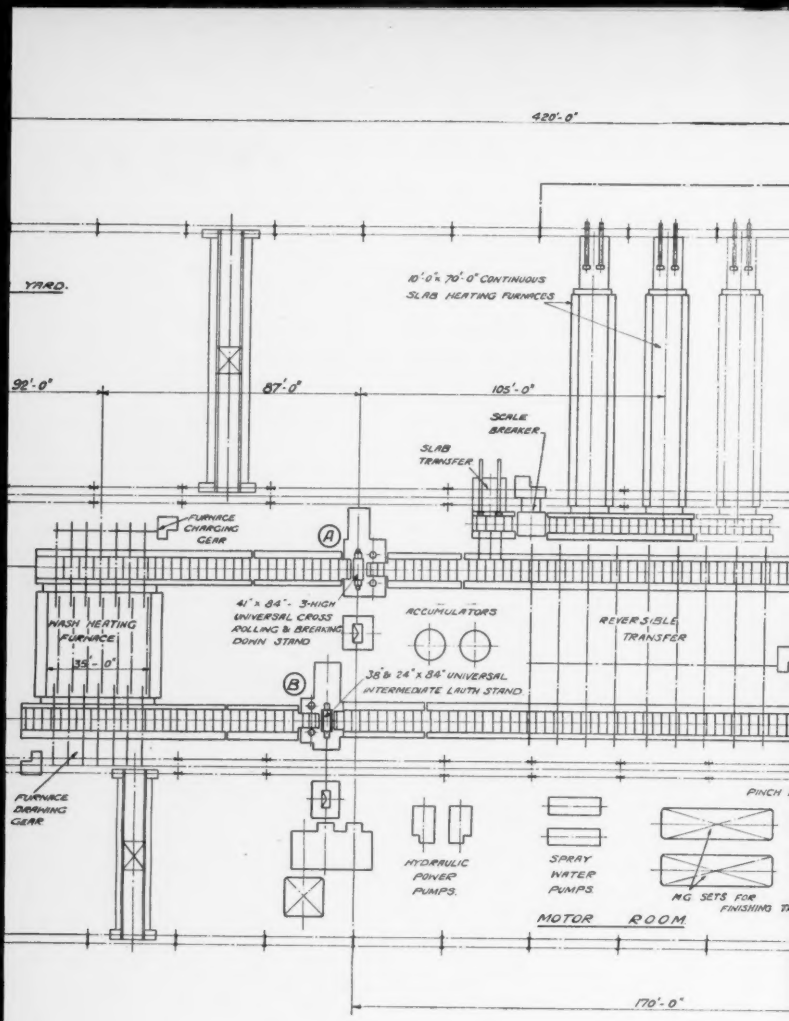

SLAB Y
92'
90'-0"
ROLL
CONDITIONING
& STORAGE
SPACE.
90'-0"
32'-0"
90'-0"


420'-0"
YARD.
10'-0" x 70'-0" CONTINUOUS SLAB HEATING FURNACES
92'-0"
87'-0"
105'-0"
SCALE BREAKER
SLAB TRANSFER
FURNACE CHARGING GEAR
A
WASH HEATING FURNACE
35'-0"
41" x 84" - 3-HIGH UNIVERSAL CROSS ROLLING & BREAKING DOWN STAND
ACCUMULATORS
REVERSIBLE TRANSFER
B
38" & 24" x 84" UNIVERSAL INTERMEDIATE LAUTH STAND
FURNACE DRAWING GEAR
HYDRAULIC POWER PUMPS.
SPRAY WATER PUMPS.
M.G. SETS FOR
MOTOR ROOM
170'-0"

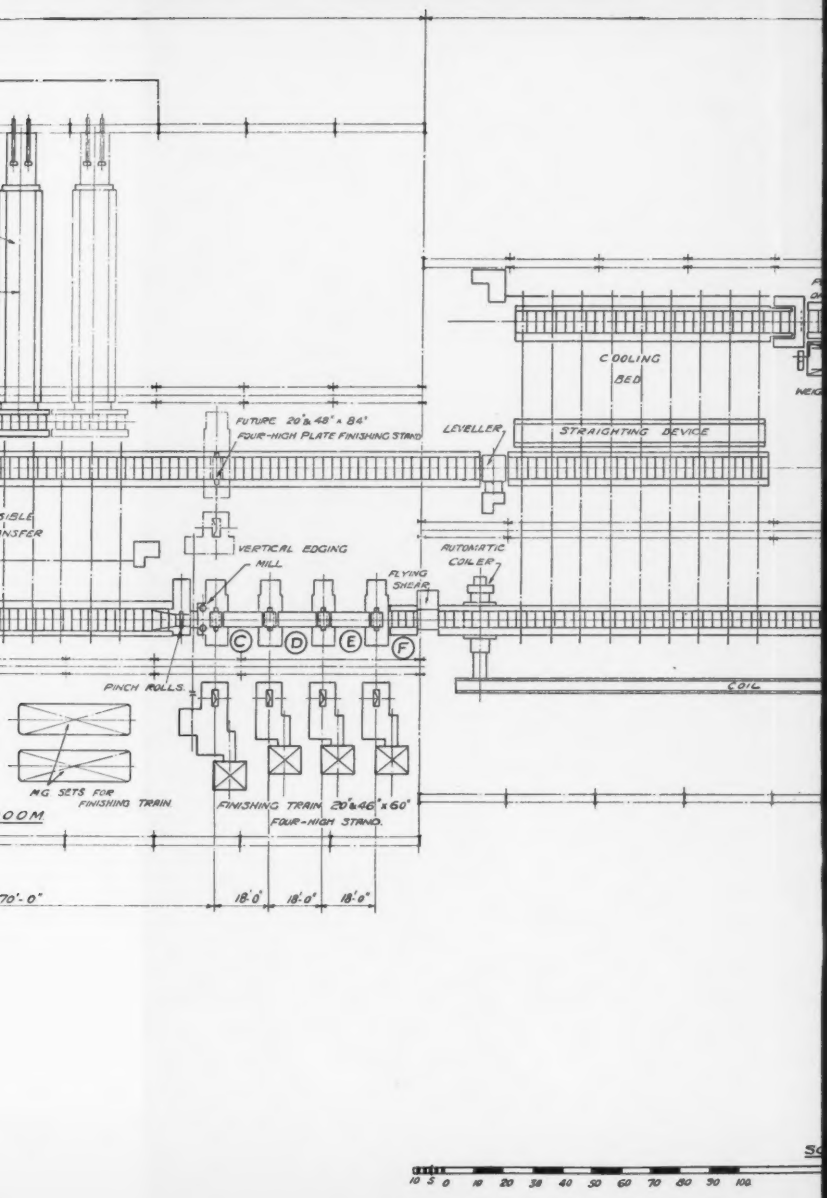
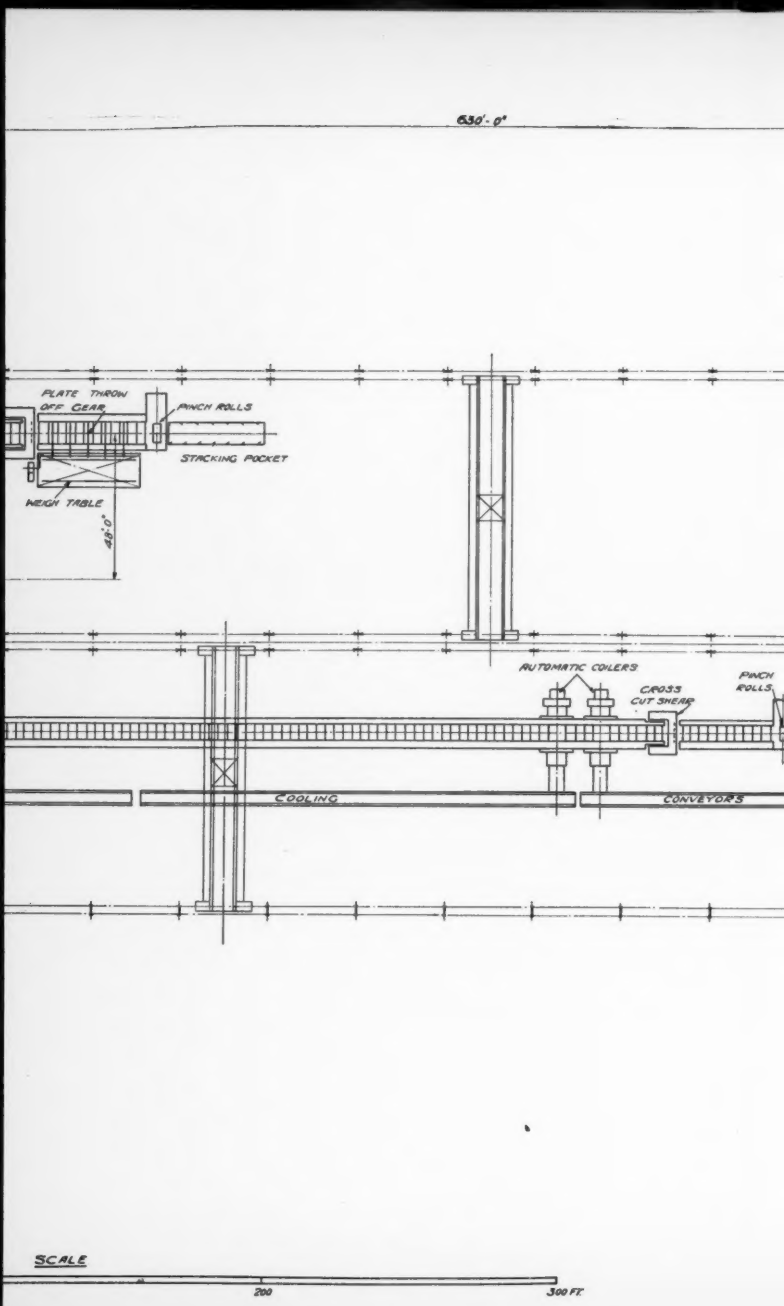
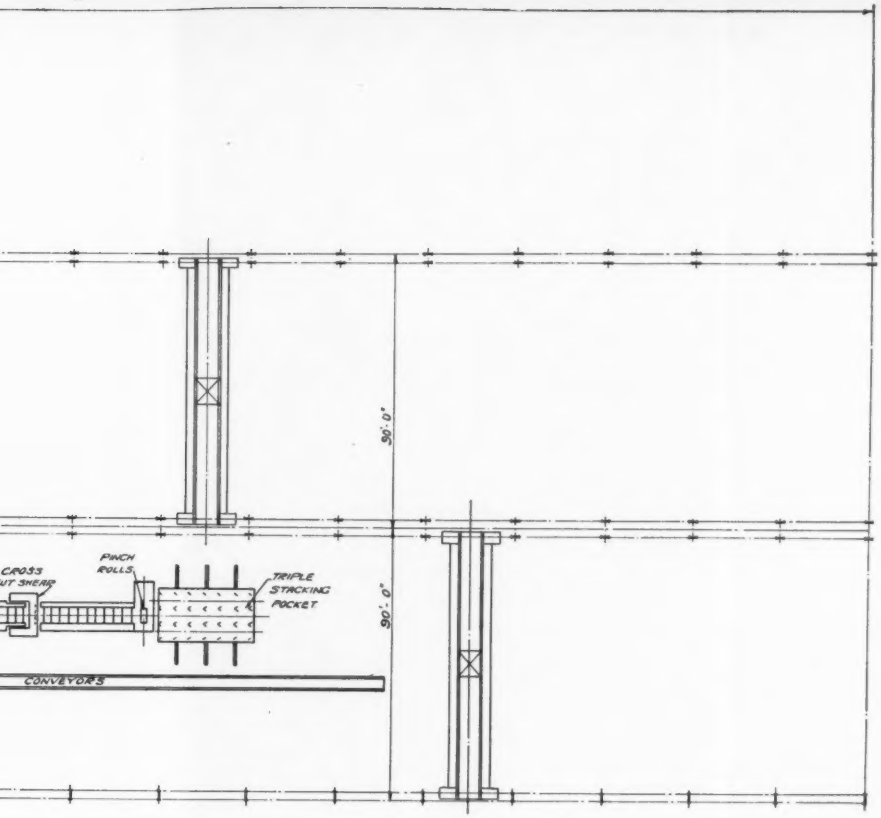


FIG. 2.—Semi-Continuous Wide-Strip Mill Plant,



Plant, with cross-rolling facilities.


30'-0"
PINCH ROLLS
TRIPLE STACKING POCKET
30'-0"
CONVEYORS

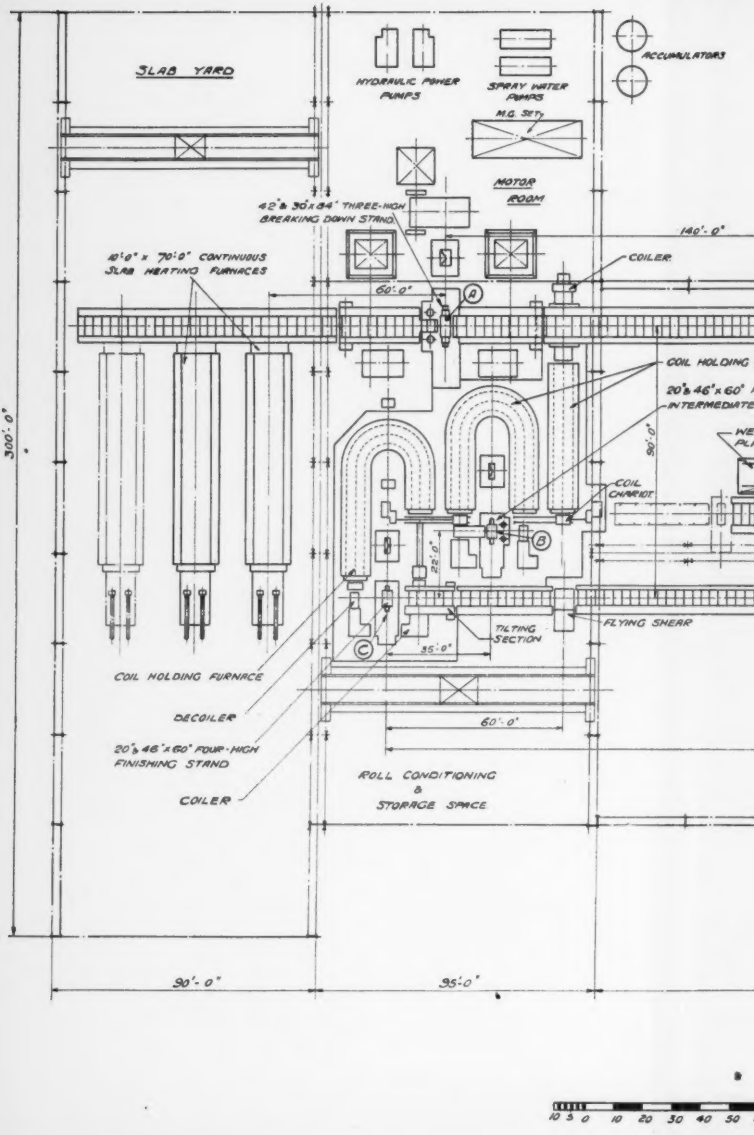

SLAB YARD
HYDRAULIC POWER PUMPS
SPRAY WATER PUMPS
ACCUMULATORS
M.G. SETS
MOTOR ROOM
42"& 30"x 84" THREE-HIGH BREAKING DOWN STAND
140'-0"
40'-0" x 70'-0" CONTINUOUS SLAB HEATING FURNACES
COILER
60'-0"
COIL HOLDING
20"& 46"x 60"
INTERMEDIATE
90'-0"
COIL CHARIOT
22'-0"
FLYING SHEAR
TILTING SECTION
35'-0"
COIL HOLDING FURNACE
DECOILER
20"& 46"x 60" FOUR-HIGH FINISHING STAND
COILER
60'-0"
ROLL CONDITIONING & STORAGE SPACE
300'-0"
90'-0"
95'-0"
10 5 0 10 20 30 40 50

FIG. 3.—V

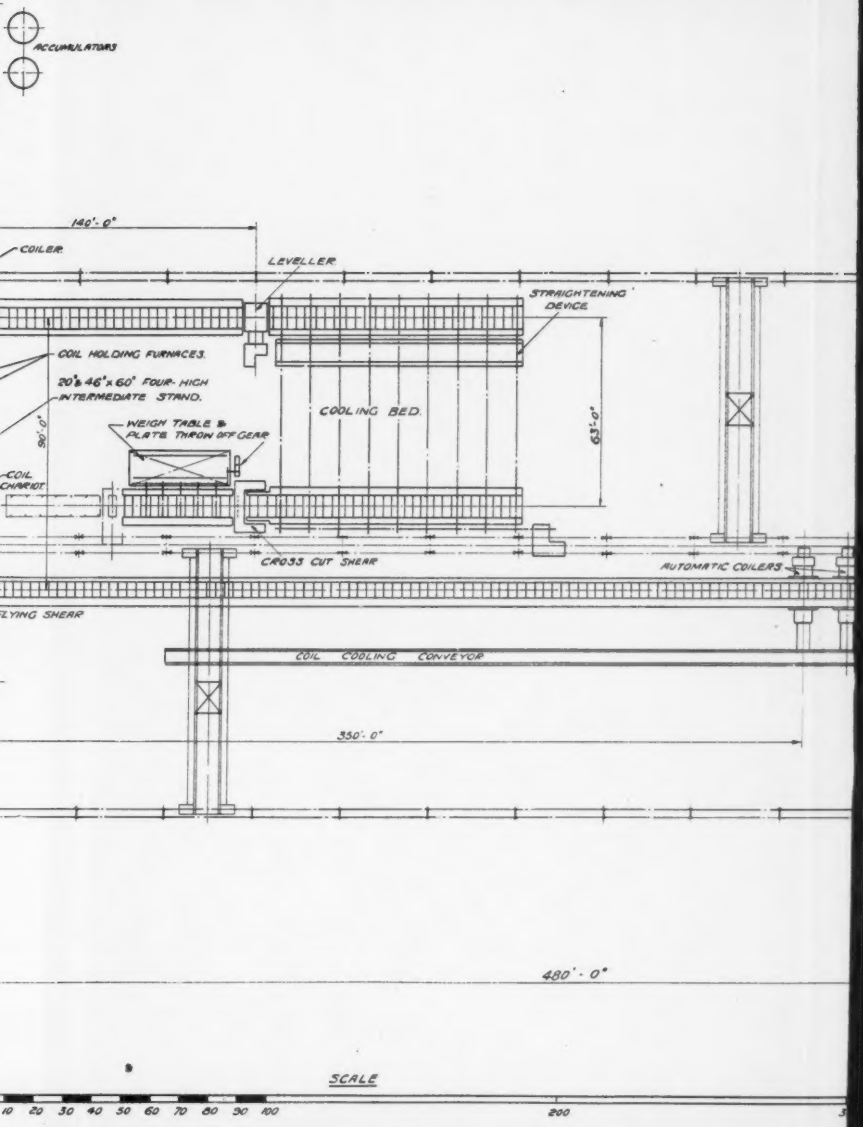


FIG. 3.—Wide-Strip Mill Plant with batch rolling and inter-pass reheating.

PLATE III.

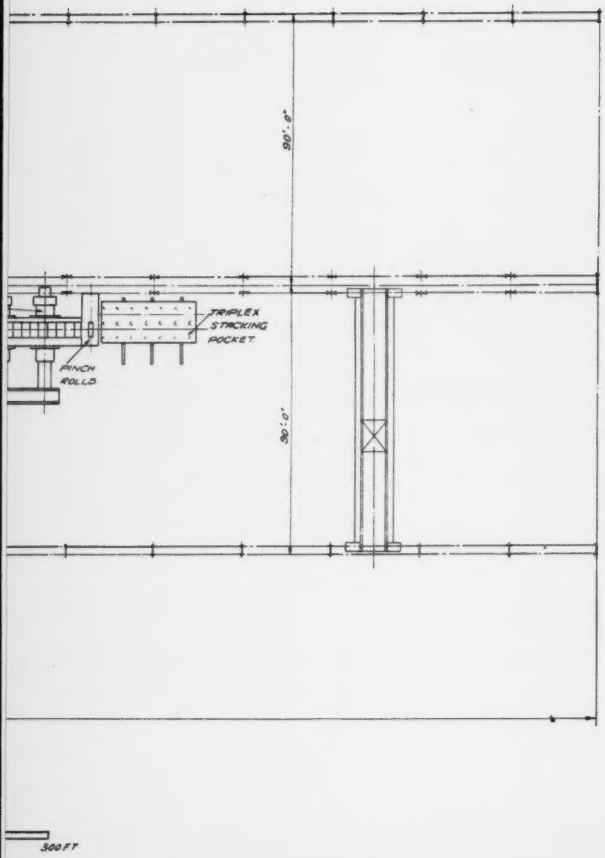


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TABLE II.—*Second Project—Principal Characteristics.*

Productive Capacity.

Productive capacity per annum	200,000 tons.
Working weeks per annum	50
Average weekly output	4,000 tons.
Number of working shifts per week	15
Working hours per shift	8
Working hours per week	120
Average hourly output	33·5 tons.
Designed maximum hourly output to allow for delays, breakdowns, and roll changing	40 tons.

Products.

Universal plates up to 72 in. wide and $\frac{3}{4}$ in. thick.
Strip in coils or flats up to 54 in. wide and down to 16 gauge; narrower strip up to 40 in. wide down to 18 gauge.
Bar-plate, sheet mill "breakdowns," and skelp within the foregoing dimensions.

Roll Stands and Drives.

Ref. Letter.	Type and Designation.	Roll Dimensions. In.	Speed. R.p.m.	Driving Motor. H.p.	Driving Motor. R.p.m.
A.	Trio-universal cross-rolling and first roughing.	41 × 84	15	6,000	570
B.	Trio-universal intermediate.	38 and 24 × 84	45		
C.	Universal four-high 1st continuous.	20 and 46 × 60	52–104	3,500	250–500
D.	Four-high 2nd continuous.	20 and 46 × 60	64–128	3,500	250–500
E.	Four-high 3rd continuous.	20 and 46 × 60	80–160	3,500	250–500
F.	Four-high 4th continuous.	20 and 46 × 60	95–190	3,500	250–500

Capital Cost.—Summary.

	£
(*a*) Mill plant, furnaces, and auxiliary productive equipment	283,620
(*b*) Electrical plant, including main and auxiliary drives, cables, transformers, and sub-station equipment	117,130
(*c*) General services; steam, water, gas, compressed air, hydraulic power and spray water	26,150
(*d*) Cranes and other materials—handling equipment	19,350
(*e*) Buildings, foundations, sewers, service tunnels, rail connections, roads, and other civil engineering work	152,160
(*f*) Miscellaneous items; roll conditioning equipment, offices, welfare provisions, &c.	16,650
Total	£615,060

Standing Charges.

13½% on total cost = £83,030
= 8*s.* 4*d.* per ton based on rated capacity.

Third Project.—Reflection upon the problems associated with the introduction of wide-strip production into Great Britain has led the author to propose certain innovations in practice which would appear helpful in meeting the requirements peculiar to the British industry. This project incorporates these developments, for some of which patent protection is being sought. The resulting plant depicted in Fig. 3 (Plate III.) may be contrasted with the installation just considered (Fig. 2), as the range of production is similar and the productive capacity only slightly smaller.

It will be apparent from what has already been said that the efficiency of stand utilisation has a great bearing upon the capital cost of wide-strip mill plants. While it has been demonstrated to be feasible to effect the whole reduction from slab to strip with a single stand,[1] and thus secure the maximum degree of stand utilisation, there are important operating advantages in sub-dividing the work among at least two, and—when the output warrants—three stands. Even the latter number represents a very substantial reduction compared with the number of stands common with continuous mills. The previous projects have gone some way in this direction without exhausting the possibilities.

Again, the desirability of definite control of the strip temperature during reduction will, it is believed, be appreciated, owing to its favourable influence on the quality of the product and upon the ability to roll to thin gauges, and consequently deliver directly from the hot-strip mill certain lines that would otherwise necessitate cold-reduction or final rolling by sheet-mill methods.

These considerations form the bases for the dispositions indicated in Fig. 3. The installation comprises three stands. For breaking down, including cross-rolling when necessary, a three-high universal mill, generally resembling the first stand of the second project except for a higher rolling speed, is envisaged. This stand serves for reducing strip stock down to a maximum of about 0·625 in. and also for rolling plate orders. The intermediate and finishing stands are straightforward four-high non-reversing mills, but, instead of being served by roller tables, each is provided with a decoiler, scaling and feed roll unit on the ingoing side, and a coiler on the outgoing. The finishing stand also delivers on to a run-out roller table, the portion adjoining the mill being formed as a tilting section capable of being rapidly raised clear at will. Stock destined for strip production is coiled after breaking down, and each coil is discharged into a tunnel furnace leading to the intermediate stand. Connecting the entry and delivery sides of the intermediate and finishing stands, and providing a coil track between them, is a U-shaped coil reheating furnace of sufficient length to take any desired maximum number of coils as a rolling batch, with a given reheating time. These furnaces have removable sectional roofs to give access to the interiors. The

[1] *See*, for example, an article entitled "Hot Strip Steel Rolled on Steckel-Type Mill." *Iron Age*, 1935, vol. 136, June 27, pp. 12–17, 78.

coils travel on two rows of small conical dead rollers made of heat-resisting alloy and carried in frames of similar material. They are moved by a reciprocating conveyor with dipping fingers engaging the lower edges of the coils. The conveyor is operated by a variable-stroke gear, to allow different numbers and widths of coil to be treated in one batch, and it is located under the furnace with the finger carriers projecting through a narrow and partially sealed slot in the furnace hearth. The furnaces may be heated in any convenient manner, but, in view of the temperatures involved (950° C. as a maximum) and the importance of precision in control, the merits of electricity should lead to its adoption, provided that current is sufficiently cheap. The furnaces are charged and drawn by quick-acting pushers independent of their conveying mechanisms.

In operating this plant, considerable latitude in the distribution of work between the stands is permissible. The primary objective would be so to split up the reduction between the three stands that they are in " balance." If this is done it will be found that the rate of wear of the finishing rolls is not unduly rapid. As an example, the production of 18-gauge strip 40 in. wide may be cited. With 4-in. slabs weighing 2·5 tons nine passes would be taken at the breaking-down stand to reach a thickness of 0·3 in. Four passes would be made at the intermediate stand, reducing the stock to 0·08 in. The finishing stand would give the two final passes to bring the strip down to 0·049 in. Each stage in this scheme of production would occupy approximately three minutes.

The inherent advantage possessed by batch-rolling in securing uniformity of gauge may be emphasised. This is especially pronounced as regards strip-to-strip variation, owing to the comparatively small amount of roll adjustment entailed. The combination of batch-rolling with intermediate heating affords the greatest degree of controllability, so that any desired physical characteristics in the strip are obtainable.

The disposal arrangements for the products of this plant are self-explanatory from the layout drawing. Owing to the smaller anticipated plate production in this case, the plate-shearing facilities are less extensive than for the previous schemes.

The summary of data concerning this installation assembled in Table III. shows that such a plant, in addition to its technical advantages, would be relatively lightly burdened with standing charges.

For smaller outputs of similar product widths (say, 50,000 tons per annum and upwards) a single four-high non-reversing stand equipped with these devices, and working in conjunction with a breaking-down mill, would make a very efficient and economic wide-strip producing unit. The drive in this instance might comprise an induction motor for the rougher, which would also be made large enough to drive the generator for the adjustable-speed D.C. machine required for the finisher. This would result in an appreciable saving in the cost of electrical equipment.

TABLE III.—*Third Project—Principal Characteristics.*

Productive Capacity.

Productive capacity per annum	185,000 tons.
Working weeks per annum	50
Average weekly output	3,700 tons.
Number of working shifts per week	15
Working hours per shift	8
Working hours per week	120
Average hourly output	30·8 tons.
Designed maximum hourly output to allow for delays, breakdowns, and roll changing	36 tons.

Products.

Universal plates up to 72 in. wide and ¾ in. thick.
Strip in coils or flats up to 54 in. wide and down to 16 gauge; narrower strip from 24 to 40 in. wide down to 18 gauge.
Bar-plate, sheet-mill "breakdowns" and skelp within the foregoing dimensions.

Roll Stands and Drives.

Ref. Letter.	Type and Designation.	Roll Dimensions. In.	Speed. R.p.m.	Driving Motor. H.p.	Driving Motor. R.p.m.
A.	Trio-universal cross-rolling and roughing.	42 and 30 × 84	24	4,000	570
B.	Universal four-high intermediate batch-rolling.	20 and 46 × 60	48–96	3,500	250–500
C.	Four-high finishing batch-rolling.	20 and 46 × 60	95–190	3,500	250–500

Capital Cost.—Summary.

	£
(*a*) Mill plant, furnaces, and auxiliary productive equipment	193,500
(*b*) Electrical plant, including main and auxiliary drives, cables, transformers, and sub-station equipment	74,080
(*c*) General services; steam, water, gas, compressed air, hydraulic power and spray water	17,800
(*d*) Cranes and other materials—handling equipment	15,000
(*e*) Buildings, foundations, sewers, service tunnels, rail connections, roads, and other civil engineering work	101,360
(*f*) Miscellaneous items; roll conditioning equipment, offices, welfare provisions, &c.	16,150
Total	£417,890

Standing Charges.

13½% on total cost = £56,420
= 6*s.* 1*d.* per ton based on rated capacity.

Instead of a U-shaped coil-holding furnace, a hearth-type furnace, capable of accommodating coil batches of the desired size, may be employed. This would be located in front of the stand, and between it and the latter adequate space would be left for a revolving peel-type charging machine or analogous device to serve for transferring coils between the furnace and the decoiler and coiler of the mill.

Batch rolling is also adaptable to a reversing hot reducing stand and a convenient method is included in the patent applications pending. In this the mill is provided with combined coiling and decoiling equipment on each side of the rolls. Co-axial with the axis of coil delivery and reception of these devices are coil holding furnaces. The two furnaces are of such a length as to accommodate the desired number of coils forming a rolling batch. Facilities are envisaged for expeditiously handling the coils between the furnaces and the combination coiling and decoiling units. The heating chamber of each furnace is arranged to be rotatable in a horizontal plane. The manner of working, assuming that the stand in question is fed with flat stock, would be as follows : A succession of pieces are given their first pass in the mill and coiled on the coiler on the outgoing side. From the latter they are discharged into the corresponding holding furnace. When the batch has been thus treated the furnace is rotated through 180° and the mill is reset for the next pass with the direction of rotation of the rolls reversed. The coils, taken one at a time from the furnace, are placed in the decoiler of the mill, rolled, recoiled on the other side, and charged into the other furnace. When the batch has accumulated in this furnace it is rotated in its turn, and the same sequence of operations occurs. Alternate passes can be taken in this manner until the desired final thickness has been attained, when the strip may be discharged from the mill either in coil form for transfer to a succeeding hot reducing stand or as finished rolled stock either in coil or flat form.

The author regrets that the time at his disposal has been insufficient to allow him to explore the fascinating field of the after-processing of the hot-mill product by the various methods of cold-reduction, heat treatment, and secondary hot-rolling operations that are now available, and which offer such a wide choice to the operator. In conclusion, he would like to reiterate his obligation to the authors of the papers he has cited, and also record his thanks to Mr. A. Witherington, who was good enough to assist him with the preparation of the drawings accompanying the paper, and to Mr. H. S. Carnegie, A.M.I.E.E., of The English Electric Co., Ltd., for help in connection with his estimates of the cost of the electrical equipment of the various schemes considered.

DISCUSSION.

Mr. W. R. Barclay, O.B.E. (President, the Institute of Metals), said that, before coming to the paper itself, he would like to pay a tribute, which he had long wished to pay, to Mr. Russell, for the great mental stimulus which personally he (Mr. Barclay) had always derived from Mr. Russell's papers, and more especially to acknowledge the skill with which, over a period of some two years, Mr. Russell had collaborated with him in a highly specialised mill, which had been described [1] at a joint meeting of the Iron and Steel Institute and the Institute of Metals. Although at that time the project was new and the plant was new, there was a feeling of confidence in it, and he was glad now to be able to say that that confidence had been completely justified, not merely in the technical success of the plant, but also in the steady reduction in working costs, which was still continuing.

Coming to the present paper, the author had made a valuable and suggestive contribution to the subject, and it was particularly interesting to find that he had shown so clear a conception of the fundamental differences between the conditions in Great Britain and the United States of America. Personally, he had seen a good deal of both, and could pay the author that compliment most sincerely. Misleading comparisons had often been drawn between the two countries by writers and speakers who had adversely criticised the size and capacity of British plants as compared with American plants for sheet and strip production. It was only fair to say, however, that there had also been a tendency in the reverse direction, and to conclude that, because conditions in Great Britain were so different from those in the United States, there was no need to give any detailed consideration at all to the American high-production plants. For that reason, if for no other, he was glad that the paper had been presented, because the author had shown clearly the possibility that at least some of the advantages of large-scale equipments could be obtained even when outputs were necessarily on an appreciably smaller scale.

Comparisons of rolling-mill production between the two countries were even more pronounced in the case of non-ferrous than in the case of ferrous metals. Even in the non-ferrous field, however, in which his (Mr. Barclay's) own interests particularly lay, there was much which could be learned from these wider studies of high-production plants; and, although he was diffident about commenting in detail on the author's schemes—he was not an engineer—he thought that the paper laid down principles (and he spoke to some extent at least from experience) which no works manager or engineer in either branch of the metallurgical industry could afford to ignore.

[1] W. R. Barclay, G. A. V. Russell, and H. Williamson, *Journal of the Institute of Metals*, 1932, No. 2, p. 391.

He would like to make particular reference to the realisation, which was evident in the paper, of the importance of reheating facilities. Every works manager who had had to run rolling-mill plants had realised the serious loss in operating time due to weaknesses of one kind or another which often occurred in this vital auxiliary of hot-rolling operations. Either the reheating facilities were inadequate, or they were wrongly placed in the flow of operations. It was possibly a little unfair to ask the author, who had already given so much information, to elaborate that point, but he hoped that some day a valuable supplement to the paper would be provided in the form of a study of furnace layouts, not only for reheating, but also for the primary heating of blooms or billets.

He hoped that he might be permitted to refer in conclusion to another matter which had been brought very prominently to his notice recently, namely, the desirability of closer collaboration between the designers and builders of rolling-mill plant, and indeed of all machinery and equipment for the production of semi-manufactured metals both ferrous and non-ferrous, and the metallurgists and works managers responsible for such production. It had been said—probably with a certain measure of justification—that such collaboration was more obvious and general in countries such as Germany and the United States than it was in Great Britain. Frank discussion between engineers and metallurgists on this subject could not fail to be productive of good on both sides. The extended application of semi-manufactured products, whether sheet or strip, rolled or extruded bars, sections, profiles, &c., in the fields of ultimate consumption depended to a very large extent on the efficiency and standards of quality attained by the rolling mills, wire-drawing mills, and extrusion plants which produced them. These constituted the links between raw materials and their final application in industry. It was for that reason, as well as for the intrinsic value of the paper, that he welcomed most heartily the author's contribution, and thanked the Institute for the opportunity of taking part in the discussion.

Mr. A. Allison (Sheffield) emphasised what Mr. Barclay had said as to the value of the paper; personally, he felt that, together with the author's previous paper, it would form an important nucleus round which future developments in regard to sheet and strip manufacture would be built up. The author's schemes aimed very frankly at bringing large-scale American methods into the somewhat small-scale British manufacture; in other words, the author was of opinion that the methods adopted by very large units producing a standard product on a very large scale could be adapted to the production of small quantities of more varied products. Personally, he thought that the difficulty in such schemes was a question of environment. It was obvious that those who produced sheet did not as a rule produce strip, and it seemed

to him that the industry was so split up into sections, all more or less specialised, that the great difficulty in regard to the plants designed by the author lay in the question of the environment and the particular trade in which the firm was engaged. The schemes mentioned strip of from 24 to 54 in. in width. From his own knowledge he would put strip at a maximum width of 20 in., and he was inclined to doubt whether machinery which could produce strip 54 in. in width was the most suitable with which to roll a strip 20 or 24 in. wide. In any case, it seemed to him that the market for widths of 24 to 36 in. was not large. He was not referring to tinplates; it would be agreed, he thought, that they constituted a separate branch altogether.

It was true that there was a modern demand for coils of strip, say, 6 in. in width, and the consumer required coils of 150 lb. for serving automatic machines, but the great bulk of the trade up to the present seemed to be satisfied with coils of lighter weight, because the heavier coils of 150 lb. were somewhat unmanageable. Presumably the author's scheme would mean that if coils of 150 lb. and 6 in. wide were wanted those coils would be rolled in multiples of four; *i.e.*, the slab would weigh between 600 and 700 lb. It was quite true that that could be done, but he felt that the scope for those particular weights was somewhat limited.

He sympathised very strongly with the author's evident wish to design machinery for smaller and medium-sized industrial units rather than for huge organisations with enormous plant, because he held very strongly that the peak of economy and efficiency was reached in medium-sized plants. It had always seemed to him that in the case of gigantic installations producing a standard product, the manufacturer was dictating to the customer what the customer should buy. He believed it was Henry Ford who said, "In industry, if you give service the financial results will follow," and therefore an effort should be made to satisfy the customer by giving him the quality he desired and the widths and weights that he desired, rather than by putting down a gigantic unit to compel him to take the material which was manufactured.

He thought, moreover, that there was much greater likelihood of a plant of medium capacity being kept fully occupied than there was in the case of a very large unit.

He was not an engineer, and could not go into questions of cost, but there were a few points on which he would like to criticise the paper. Having been connected with the production side of rolling mills for a number of years, he felt that the author had been optimistic as to the amount of time worked. If anything, the author's schemes were on the large side. Presumably the author was making a compromise between the very large units and the medium- and small-sized units which were common in Great Britain; but he spoke of an average weekly output of 3500 tons, and wanted to work 50 weeks in the year. Personally, he thought the proposed amount

of time worked was overestimated, in view of the necessary maintenance time required, and if the author aimed at schemes with a maximum of, say, 1000 to 2000 tons a week, that would possibly be a more suitable size of plant for Great Britain, in view of the other processes required in conjunction with rolling, such as pickling, annealing, slitting, &c.

He felt, on looking at schemes such as those of the author, and at certain plants which he had seen, that engineers often detracted from the value of their plant by allocating far too much floor space; the unit was too spacious to be economical. There would probably be agreement that in the older works which had grown up from small units the plant was closer together, and they were more economical for that among other reasons.

The author referred to the coil-heating furnace adapted to the Steckel mill. Personally, while he had a great admiration for American designers, he felt that that system was far too frail and unreliable from the standpoint of production, and he thought that it would be very expensive in maintenance.

The author rightly drew attention to the necessity for economising by substituting flood-lubricated plain bearings for roller bearings on the rolls of large units. It should be pointed out that in the case of high-duty mills the rolls were likely to wear out very rapidly. In the case of at least one design of roller bearings, the rolls required very elaborate machining and grinding to very exact sizes. Engineers would do better to arrange their mill details so that more normal shapes and sizes of rolls could be accommodated, without having to incur the costs of elaborate machining and grinding for a tool which of necessity would be quickly worn out.

The schemes put forward were very interesting, and he felt that, as Mr. Barclay had suggested, their utility would ultimately be found as a result of collaboration between the various interests involved. These aspects—engineering, production, metallurgical, and commercial—would all have to be considered, and each contribute its quota in deciding on the scheme to be finally adopted.

Mr. Benjamin Talbot (Past-President, Middlesbrough) remarked that he was glad that the author had given a word of caution to those who watched American practice. There could be no doubt that a revolution was coming in sheet manufacture, and it had to be faced; but it was undesirable to follow blindly what had been done in America, because American outputs were so much larger, and conditions in Great Britain were entirely different. When one heard of the vast amount of capital which had already been sunk, and one might say partly lost, in America, one felt that they in Great Britain had been wise in delaying a few years while the industry there was getting over its primary difficulties.

Even the schemes suggested by the author were not small. Personally, he favoured the second, because he thought that it was

more elastic and would therefore probably serve British conditions better than the other designs. It covered light plate mills and continuous finishing, but the author had not touched upon what must follow, namely, cold-rolling down to the finished and thinner gauges; and there, of course, was another revolution.

He welcomed the paper, and thought that the author had been very wise in cautioning people in Great Britain not to follow American practice blindly.

Mr. A. W. KIEFT (London) said that the installation of rolling-mill plants for the production of wide strip of various widths and gauges was of such national importance that, before adding to the various suggestions put forward by the author, he suggested that it would have been invaluable if the author had given a more detailed analysis of the conditions at present existing in this industry in Britain and America, such as the advantages and disadvantages of installing strip plant for the production of the various grades of finish necessary in both heavy- and light-gauge sheets and tinplates, and particulars of the many types of mills in operation in America, together with output, capital costs, and costs of production. This would allow a comparison to be drawn from the conditions existing in this industry in Great Britain.

There were six or more different methods and types of hot mills in operation manufacturing hot-rolled wide strip in America :

(1) Slab spreading and straight-through tandem mills which consisted of ten stands, four-high.

(2) Straight-through tandem mills dealing with multiple slabs, with an output of 300,000 to 400,000 tons.

(3) Bloomed slab, uncut, delivered to a holding furnace, from which suitable multiples were cut off and rolled through a tandem train, eleven stands, four-high. Output 300,000 to 400,000 tons, according to width and gauge rolled.

(4) Universal plate mill, where the slabs were rolled to a light plate, and afterwards passed through four stands of a four-high tandem mill. Output 200,000 tons.

(5) Universal plate mill reducing the slab to a light plate, afterwards reduced to strip in a hot Steckel mill. Output 150,000 tons.

(6) Hot Steckel single-stand four-high mill fitted with pinch rolls and coiling furnaces. Output 75,000 tons.

It must be noted that to produce the necessary slab all plants had a universal blooming mill, which was essential for the production of a highly finished slab. The cost of such a mill, fully equipped with soaking pits, drives, &c., was approximately £200,000; the depreciation of this mill must be added to the author's figure, as few mills at present operating in Great Britain were capable of rolling the necessary slab. Owing to this initial capital outlay being so high, it was essential for economic production to put down the plant for producing hot-rolled wide-strip that would enable the largest divisor possible to be obtained, provided a suitable demand existed, as well as ensuring such resources as cheap raw material,

labour of the right type, plentiful and suitable water supplies, rail and shipping transport, and close proximity to consuming areas.

Before discussing the type of hot mill suitable for the manufacture of light plate or hot strip, it was as well to state that the tonnage of strip in suitable finishes that would be used without further processing through cold- or hot-reduction mills was a small percentage of their present manufactures, and owing to the constitution of the British Iron and Steel Federation, plates more than ¼ in. thick produced on such a mill would be opposed by the plate-rollers' section of the British steel industry. They were, in consequence, faced with the consumption of the tonnage of hot strip produced replacing the present mills operating on the various grades, sizes, and gauges in the sheet and tinplate industries.

The capacity of the present sheet mills was 85 to 100 tons per week, and of tinplate mills 50 to 65 tons. The disadvantages that arose in Great Britain were chiefly brought about owing to the decline in those industries, both of which were operating at present at only from 50 to 60% of capacity, and this position would become more pronounced as new mills were completed in Canada and Australia. It must also be realised that both those industries were enabled to operate successfully commercially only by their respective associations working to mill allocation, under penalty for over-production on sheets of 25*s*. per ton, with a pay-out of 20*s*. per ton on under-production, or in tinplate manufacture 2*s*. per box pay-in or pay-out for over- or under-production, or approximately £2 per ton.

The advantages of manufacturing sheets and tinplates from hot-rolled strip were :

(1) Better yield of finished product.
(2) More even substance distributed over individual sheets or plates.
(3) A much higher percentage of prime product.
(4) Considerably less labour employed.
(5) Better product.

The disadvantages were :

(1) The tonnage of the hot-mill product that had to be afterwards cold-rolled to replace the present type of manufactures must bear the cost of pool penalties if its output was in excess of allocation, or carry the increased depreciation and standing charges of mills at present in operation when rendered idle.
(2) Excessive capital outlay necessary to get full advantage out of the process, such as cold-reduction mills, &c.
(3) Difficulty of obtaining a sufficient number of suitable orders for continuous operation of the plant.
(4) Labour problems.

The capital costs for a continuous wide-strip mill installation for hot- and cold-reduction, together with the necessary finishing plants, could vary from £1,250,000 up to £3,500,000, in accordance with the tonnage outputs and the finishes required.

The cost of conversion of full-finish automobile body sheet on a continuous tandem hot mill and tandem cold mill, taking ingots

at £4 per gross ton, but not including depreciation, was approximately £7 5*s*., making an all-in cost of £11 5*s*. per ton f.o.t., or for tinplate ingots at £4 per ton, 14*s*. per box of 100 lb., on a tin yield of 1 lb. 4 oz. per basis box, with tin at £220 per ton.

The following advantages existed in the costs of various types of mills, taking ingots in each case at £4 per ton over and above the cost of operation on two-high hand mills, no depreciation being charged in each case, the sheets being of 20 gauge, suitable for full-finished automobile stock :

(1) Mechanised mills using sheet bar, approximately 17*s*. 6*d*. per ton.
(2) Mechanised two-high mills, using strip break-down 18*s*. 6*d*.
(3) Hot strip worked on three-high finishing mill 23*s*.
(4) Universal plate-mill finishing on tandem hot and cold mills 37*s*. 6*d*. to 39*s*.

The rejection loss (seconds) varied from 17*s*. 6*d*. per ton on the hand-operated mills down to 4*s*. on the tandem hot- and cold-rolling process.

He was of the opinion that a hot-strip mill in Great Britain should be installed by the joint associations at present engaged in the sheet and tinplate industry, such plant to be installed in the most suitable economic position, and the tonnage allocated to such mill to be divided *pro rata* to their present mill allocation. This arrangement would allow of the mill working to its full capacity on the most suitable orders, would also allow of the continuance of the pool penalties on trade allocation, and would not set up definite distress areas, as its output would be distributed over the mills operating throughout the country.

The plant he favoured would be on the lines outlined by the author in his first project, the mill being capable of rolling material up to 48 in. wide, and should consist of five stands of four-high tandem train, instead of four stands, as the tendency to place additional work on both the light universal plate mill and the four-stand tandem train was so heavy that, apart from the reduction effect on the strip produced, output was also retarded. The hot strip produced would then be available for finishing on any of the many types of mills at present installed in the country, cross-rolled or otherwise, as well as being suitable for cold-rolling in either the continuous tandem train of four-high mills, or reversing four-high mills.

The capital outlay for such a plant would not be as economical for the production obtained from such a hot mill as would be possible for the ten-stand tandem four-high hot train, but as a suitable supply of orders of the right sizes and gauges was not available in Great Britain, the output advantages of the last-mentioned mill were of no avail.

Major W. R. Brown (Swansea) said the paper seemed to be more an indication of possibilities than a practical outline of any

particular plant, and he would like to ask whether the author knew of any plant in Great Britain or any other country, on ferrous or non-ferrous work, applying any of the innovations which he suggested. Personally, he believed that it was by practical experience that most knowledge was gained.

Obviously the author had presented his paper in order to draw criticism, and he was entitled to receive it. If one took any one of his schemes, and particularly the last one, it would be found in practice that to control the quality of the steel would be extremely difficult. The reheating furnace idea was satisfactory from the point of view of keeping the heat in the steel, but all kinds of qualities would be created which were not always wanted; and anyone who had visited the United States or who had read the literature giving some of the difficulties would realise what his point was there. One could often get steel which was too soft for most practical purposes. One of the difficulties to which reference had already been made was that any mill in Great Britain would be faced with the complex problem of finding an existing market for any considerable tonnage of any particular kind. Any strip mill operating in Great Britain would for a long time have to make all kinds of products and create new markets. The difficulties were going to be much greater than those encountered in America.

The author suggested the use of coil furnaces, but did not give any time factors, and the time factor was all-important in a strip mill; it controlled the whole set-out. The author would probably get jamming in his coil furnaces, because of the U-shape design, nor were they long enough for complete heat penetration and soaking right through to give the kind of rolling required; and if there was not equal heating all the way through, the product would be poor; there would be thin ends and uneven gauge throughout. It was beyond question that a strip mill of the American type, producing 700,000 tons a year, was not a practical possibility as yet in Great Britain, and every manufacturer, particularly in South Wales, was waiting with the utmost anxiety for alternative schemes. Personally, he thought that the author's plant was too big for South Wales, because the finishing departments necessary to finish off into tinplate the tonnage which would be presented to them would involve millions of capital. The operating cost of the author's mill, moreover, would be considerably higher than that of an American straight-through mill; the handling would be very considerable, and the maintenance, with all the additional appliances used, would be higher, so that there would be added cost not only in direct rolling, but also in maintenance as well.

He did not agree with the width of strip suggested by the author. One of the difficulties in Great Britain was that if strip was going to be extensively used, it would be necessary to roll much wider strip. He had in mind the automobile industry, which was demanding widths of round about 90 in. The automobile market was the one

market above all others which offered the greatest existing tonnage and possible increased tonnage, and the most favourable prices.

Nevertheless, the author had been very courageous, particularly in his third scheme, in putting an entirely new proposition in front of the industry, and it was such new and courageous suggestions which were the stepping-stones to the practical possibilities of the future. He was very grateful, therefore, to the author for his courage.

CORRESPONDENCE.

Mr. P. DAMIRON (Paris, France) wrote that he wished to extend his congratulations to Mr. Russell for his important contribution to the study of strip-steel manufacture from a European point of view.

He had noted with interest Mr. Russell's remarks concerning the important differences in conditions in the exploitation of strip mills. The fact that Mr. Russell had very seriously called their attention to the standing charges, namely, interest on, and depreciation of, any new strip-rolling mill installation, led him to express his opinion and to formulate some ideas in reply to Mr. Russell's paper.

If the engineer in charge of the design of strip mills to be built in England, and more generally in Europe, had primarily to take into consideration the final costs obtained with these mills, which would work under European conditions, *i.e.*, with smaller tonnages and a greater variety of sizes and qualities than in the U.S.A., there was one point on which it seemed to him that there should be no inferiority of the European realisations compared with the American ones; it was the final quality of the strip rolled. As far as the quality of the strip was concerned, the writer thought that it was even more important to adopt in Europe the same high standards as obtained in America, than to realise some economies in connection with the building or the operation of the mill.

He had had occasion to take part in many conversations with American users of strip in the past years, and more especially during a visit he had made to the U.S.A. recently, and in particular he had discussed the question of the customary specifications used on the strip market. From these conversations, it emerged that the most important points of those specifications might be summarised as follows :

(1) Quality of the metal.
(2) Range of widths and thicknesses available.
(3) Weight of the coils.
(4) Evenness of gauge across the section and along the strip.
(5) Surface condition.
(6) Conditions of the edges.

The importance of the quality of the steel would not be dis-

cussed, as it was known that many of the European steelworks were able to produce excellent qualities of steel.

With regard to the sizes, he thought that Mr. Russell had given valuable information to future European strip rollers in suggesting that they limited the width of the strip to about 48–54 in.

With regard to the thicknesses, Mr. Russell indicated that in some of the latest strip mills in America, like the McDonald mill of the Carnegie-Illinois Steel Corp., it was possible to go as low as 18 gauge. In fact, in this mill, which was so far the latest one built in the U.S.A., it had been possible to go as low as 20 gauge on 36-in. wide strip.

With one of the existing Steckel hot mills, it had been possible to obtain 16 gauge.

The third requirement related to the weight of the coils, and in this connection he found it necessary to express an opinion which was quite different from Mr. Russell's viewpoint.

Mr. Russell indicated in Section *A* of his paper, dealing with primary product conditions, that the tendency in the more recent American wide-strip mills was to increase the weight per foot of width of the strip, and he explained that certain disadvantages resulted from this, which would make the importance of this factor doubtful in the case of European mills. Further, in discussing the characteristics of his proposed mill layouts, Mr. Russell expressed the opinion that a coil weight up to 1000 lb. per ft. of width would be satisfactory. The opinion of practically all American engineers the writer had met, and with whom he had discussed the problems in connection with the subsequent use of hot-rolled strip, and more especially the cold-rolling, was that it was essential for the cold-rolling plant to obtain as heavy a coil as possible.

The advantage of a very long coil of hot-rolled strip lay, in the first place, in a considerable economy in the cold-rolling operation. The majority of the cold mills working in the U.S.A. at present were of the reversible single-stand, partly pulled, partly driven type. This type of mill started at a low speed, and after the pressure to be applied had been regulated, a very high speed was obtained through an improved flexible electric drive.

The longer the mill worked at high speed, the greater was the output for the same amount of reduction given to the strip. The main loss of time in the cold-rolling operation was due to the necessity of reversing the mill and starting the new pass again, with the corresponding regulation of the screwdown. In addition to this there were always at the ends of a cold-rolled coil, two parts which were slightly off gauge. This referred to the parts of the coils remaining between the mill coiler and the working rolls. There was no type of mill so far which avoided this inconvenience entirely, and the longer the coil, the smaller, finally, was this percentage of off-gauge material.

Mr. Russell suggested that if it should be necessary to have heavy

coils, they might be obtained from smaller coils welded together. The writer had had the occasion to investigate this process very carefully, and had found that not only was its application very costly, but that it also caused considerable trouble, for the following reasons :

It was very difficult to find two coils to be welded together having exactly the same gauge, and, moreover, the same variation of gauge across the width of the strip. That was the first difficulty when the strip was to be cold-rolled. Another difficulty was that the modern cold-rolling mills, which had a very high production, and which for that reason were economical in operation, used a considerable pull on the strip and a braking action on the back coiler, in order to facilitate the reduction of thickness between the working rolls. This method was applied mainly on the Steckel all-pull type cold mills, but since the Steckel cold mills had proved the considerable value of this pull action, all cold mills were using this method to a greater or less extent. If a considerable pull was applied to a welded strip, and if the welded part in addition to that pull had to withstand the reduction of thickness due to the rolling action, the result would be a considerable percentage of breakages in the welded part itself, or in its immediate neighbourhood, wherever there was a difference of size in the metal crystals. For all these reasons the writer insisted on the great importance of obtaining heavy coils of at least 2000 lb. per ft. of width.

Regarding the three projects presented by Mr. Russell, and accepting the sizes and the annual capacities given, he wished to present the following remarks :

As far as the first project was concerned, he thought that there would be a considerable loss of time due to the transfer of the plates to the entrance of the wash-heating furnace. He also believed that it would be difficult to maintain a constant atmosphere in such a very wide furnace (Mr. Russell indicated 35 ft.), and it would also have a very high maintenance cost.

In this same first project, Mr. Russell made provision for four four-high finishing stands after the universal mill. This mill would be very expensive to instal, not only from the point of view of the mechanical features, but also the electrical part, as it included four D.C. motors having a total of 11,000 h.p., with the necessary electrical equipment for providing the variation of speed between the motors, and the wide range of flexibility necessary for operating any mills working on the continuous system. If the reversing universal breakdown mill as provided in the first project of Mr. Russell was followed by a four-high single-stand hot mill of the Steckel type, like the mill installed by the Youngstown Sheet and Tube Co. at their Indiana Harbour plant, he supposed that this would avoid the necessity of installing a wash-heating furnace, and would enable the four-stand finishing mill to be replaced by one reversible four-high stand.

It seemed to the writer that the necessary capital, which had been estimated by Mr. Russell at £513,570, would be decreased by at least £100,000, with, moreover, the possibility of obtaining coils having at least double the weight per foot of width estimated in the original first project (more than 2000 lb. per ft. of width instead of 1000 lb.).

The same observation applied to the second project, as the difference between the first and second schemes lay more in the possibility of making a wider range of plates than in the modification of the output of the strip mill itself.

With regard to the third project, which was an entirely new type of mill, he wished to congratulate Mr. Russell for having developed this new scheme. Knowing how difficult were new developments of this kind, without adapting the types of mills previously invented, he fully appreciated the effort of Mr. Russell. It seemed to him, however, that there were features in the scheme presented which would create some difficulties when using that type of mill. The first point was that the coil-holding furnaces would have to reheat very large and heavy coils, and that would make it difficult to obtain in these furnaces an even reheating of the different parts of the coil. If there was even a slight difference of temperature between the sides of the strip and the centre, the rolling operation would be entirely unsuccessful. This remark was based more particularly on the fact that the writer had been present at an accident to the first experimental Steckel hot mill which was built in America some years ago. Owing to the heating of a bearing in the mill it had been necessary at that time to hold the coil in one of the coiling furnaces for about 10 min. Although care had immediately been taken to lower the temperature of the coiling furnace, the sides were hotter than the centre when the coil left the furnace (to obtain even heating of a heavy coil, it would be necessary to hold the coil at least 4 or 5 hr. in a well-regulated furnace), and it was impossible to roll the strip correctly, as there was a considerable waving of the sides, owing to the higher temperature.

His second observation on Mr. Russell's last scheme was that since—particularly in Europe—a hot-strip mill would have to face a rolling programme which would include many different sizes, it would be very difficult for the rollers to apply the exact amount of rolling fixed for any coil, and then remember the subsequent rolling programme to be applied to the same coil after it came out of the furnace half an hour or an hour later.

For the same reason, if for certain orders it was desired to use rolls having a very high finish, it would be impossible to do so in a mill where between the passes given to certain coils a large amount of other coils were rolled. They all knew that unfortunately the condition of the rolls changed very rapidly, and that newly ground rolls very soon lost their beautiful surface during the hot-rolling process. That made it necessary in every mill to reserve fresh rolls for orders where the surface quality was specially important.

In closing, he wished to express the hope that European countries might benefit from the experience gained in the United States by years of careful study and with expensive constructions, even if in Europe the scale of production was considerably smaller and the variety of sizes greater. He hoped that the first European strip mills started would be a great success, and to obtain that result he thought it essential that they should make the main point of their programme the highest specifications of quality actually obtained in America. The tonnages would be smaller, but the strip should be as good as the best American product.

Mr. A. O. MORGAN (Briton Ferry) wrote that strip-sheet rolling had for some time occupied the attention of all engaged in the steel-sheet trade of Great Britain, and Mr. Russell's contribution to the information on that subject was valuable to all concerned.

Most of them would agree that the semi-continuous types of mills shown in the author's paper were more suitable for the jobbing orders obtaining in Great Britain, and in the writer's opinion No. 2 type was the most suitable for the general run of work in South Wales, as it had greater flexibility of product. It would give not only a reasonably wide strip without undue reheating, but also with the addition of suitable two- or three-high hot mills fitted with mechanical catcher tables it could supply any demand which might arise for large or small quantities of odd sizes of varying substance and above the width of the strip itself.

There were two points which were not made quite clear in the paper, and they were : To what extent could reduction be made in that mill with the one wash-heating furnace—in other words, what was the maximum thickness of slab which could be sent to the wash-heating furnace and afterwards rolled in the intermediate mill and the four-stand finishing train down to 18 gauge; also, at what temperature was the steel likely to enter the first of the four finishing stands ?

Another advantage of this type of mill was that it required less power to operate than the continuous American type ; unless power could be obtained at a reasonable figure from a public supply company, the capital expenditure in putting down a power plant was excessive, and the grid supply, even when near at hand and where a definite shortage of load existed, had, to the writer's knowledge, been unobtainable, or only offered at a ridiculous price. They had heard a great deal about the American strip mill and its tremendous output, but it would be interesting to know—and perhaps Mr. Russell could tell them—what percentage of possible output was obtained year in and year out.

The author mentioned in a footnote near the beginning of his paper that the standing charges on an 80-in. American mill with a possible output of 600,000 tons per annum would be over 9*s*. per ton under favourable conditions, which the writer assumed to be 90%

of possible output, but that these charges would approach 17*s.* per ton should production decline by 45%. The first question which these figures prompted was: What would be the average production obtainable with the jobbing orders appertaining to Great Britain, and to South Wales in particular?

The comparative costs of the three types of mills shown were interesting, and No. 3 type certainly deserved consideration for its low capital cost and consequent low standing charges per ton of material rolled. There were, however, some disadvantages arising from this design of mill. The three reheats of the strip would lead to steel losses, and though they might tend to lower the power consumption, the coal cost for reheating would be an appreciable figure, and the handling costs would be higher than those of the second design. This third design of mill might, however, if certain patent rights precluded the common use of continuous stands for wide strip, be a means of circumventing these patents.

Mr. J. A. SMEETON (London), wrote that he had read the author's paper with very considerable interest and pleasure. The paper offered the first lucid information which had been presented to the iron and steel industry upon a subject of the greatest importance, and which had been occupying the thoughtful consideration for some years of the sheet and tinplate manufacturers, not only of Great Britain but of Europe and all countries abroad, and outside the U.S.A.

During the last eight or nine years, in fact ever since the first continuous wide-strip rolling mill plant was installed in the U.S.A., the leading British manufacturers and their technical experts had made frequent visits to America, presumably to discover the possibility and advisability of installing similar plants in Great Britain, but nothing had resulted until recently, when it had been stated that a large plant of American design and output was contemplated, if not actually ordered, by one of the largest British sheet and tinplate combines.

It was not the writer's intention to criticise the advisability of installing such a plant in Great Britain, but he would suggest that if the said company had not definitely committed themselves they should very carefully study the author's paper, and especially his suggestions relating to modified layouts suitable for European conditions.

It might not be generally known that a modified continuous plant embodying the best and most suitable American principles was now being installed in Germany by the Vereinigte Stahlwerke, and it was expected that it would be running by the end of this year. The tonnage throughput expected from the plant was about 200,000 tons per annum. The author did not appear to have referred to this German installation, for which the writer was sorry, as it would have been interesting to British manufacturers to know what their

Continental competitors were doing to modernise their sheet and tinplate production by using strip instead of bars.

He did not propose to attempt to criticise in any sense the three very practical layouts suggested by the author, as each one did, in his opinion, suit the varying conditions of products to be produced at a minimum cost and with a maximum elasticity of production.

He would, however, like to ask the author whether he had satisfied himself as to the possibility of obtaining in Great Britain suitable and sufficient supplies of ingots, billets, or slabs of consistent quality from which a continuous satisfactory long strip could be rolled. He was afraid that this ingot problem would be a serious one, especially when imported ores had to be used to feed the blast-furnaces, or when open-market pig iron and scrap were fed to the melting furnaces.

Assuming this difficult obstacle was overcome, the next and probably the most complicated problem, which was hardly referred to by the author, was that of suitable rolls for the four-high hot- and cold-rolling mills. He was informed on good authority that in America at the large continuous strip mills they had completely to change their hot-mill rolls every seven hours, and they accelerated the process by mounting the four rolls in a cage which was secured in the housing and was, therefore, easily removed in a minimum time, *viz.*, in the hour between shifts.

It would be obvious from this that the roll quality question was probably extremely important, and he was informed that every maker of steel and cast-iron rolls in America and also on the Continent and in Great Britain was now spending large sums of money in practical research to find rolls of suitable and economical productive quality to justify the installation of four-high hot- and cold-rolling mills. The main feature of this roll problem was to make a roll not too large in diameter and weight, with sufficient surface hardness and body toughness to stand up to the very heavy draft strains which were imposed on modern four-high mills. Both the working and the backing rolls offered equal difficulties of solution.

Having solved these and other mill problems, such as suitable bearings, one arrived at what might be considered in all producing countries as a major consideration, namely, that of labour. Throughout the whole world they had the serious question of unemployment, a considerable proportion of which was due to the evolutionary development of mechanisation, and which applied to every productive industry, but probably more to the iron and steel industry than any other, and to the sheet and tinplate portion of that industry particularly.

For many more years than the author had lived the sheet and tinplate mills and auxiliary plant had remained the same, and practically the same number of men per mill unit were employed to-day as were employed fifty years ago. It had been found practically impossible to instal any labour-saving mechanism into

these industries, owing to the fact that hard-and-fast trade union regulations had made it impossible to reduce the number of men and/or women employed per mill. By comparison, at the Inland Works, U.S.A., where they were working a large continuous wide-strip mill plant, they produced 28,000 tons of wide strip monthly, *i.e.*, 336,000 tons per annum. On the mill and furnace plant they employed 76 men per shift, including thirteen electricians, *i.e.*, 228 men per day. To produce a similar tonnage by the present British methods it was necessary to employ approximately 2000 men, which meant that one such plant would put out of work nearly 1800 men.

As only by this means of reducing expensive manual labour could the high cost of these modern plants be economically justified, this question became one not only of iron and steel trade policy, but also of national policy.

He thought, therefore, that some less drastic means of producing more economically both sheets and tinplate would inevitably have to be adopted in Great Britain, otherwise they would have the whole of the British production being made in two or three works, and all other works entirely idle.

Such alternative modified solutions were possible, and were being both considered and adopted by a number of sheet works in Great Britain, where a great variation in quality, size, and gauge of sheets had to be produced, and where the larger plants, the subject of the author's paper, were unsuitable, owing to the comparatively smaller tonnage throughput called for, as only production on a large scale of wide strip could possibly justify such expensive installations as formed the subject of the paper under discussion.

Mr. G. M. Brown (Sheffield) wrote that the paper by Mr. Russell was timely and interesting, and, together with that submitted by Edwards and his co-workers, it formed an intriguing commentary on the present situation in Great Britain.

There was a growing demand for high-class deep-drawing material in the form of sheet and strip, and it seemed probable that, although the actual market was not as yet very great, it would grow rapidly when the cold-rolled and treated products of a continuous wide-strip mill became available.

Efforts were being made, and doubtless would continue to be made, by the owners of existing sheet and tinplate mills to modernise their plants and increase both output and quality, but it did not seem that they would ever be able to compete effectively with the product of the type of mill described by the author, when backed by suitable cold-rolling and other processing equipment, particularly as regards uniformity of gauge.

The author pointed out that although the cross-sectional accuracy of the product delivered by wide-strip mills was superior to that of every other type of mill, variations in longitudinal gauge could be a serious problem; this applied also to the ordinary type of strip mill

rolling comparatively short lengths instead of long coils, and was a general limitation to the length it was advisable to produce in such mills.

It was true that really wide strip was not required in long lengths, but such lengths were surely convenient in the subsequent pickling and cold-rolling processes incidental to the production of high-grade sheets, and considerable judgment was evidently called for in making a decision as to how far it was desirable to proceed in that direction. A coil weight of 1000 lb. per ft. of width represented a length of 400 ft. in 16-gauge and more than 2000 ft. in 30-gauge material, whereas a coil of 3600 lb. per ft. of width would be considerably over 7000 ft. long. Apart from the difficulty of handling such heavy coils without damage, it did not seem that there would be any demand for them for the manufacture of cans or other receptacles.

In the McDonald 43-in. mill the slabs used were 30 ft. long, but in a wider mill where cross rolling would be necessary a much shorter, and therefore a lighter slab would have to be used, and the question of excessive weight and length of coil would not arise; in fact, in such a case there would be some inducement to utilise the thickest slab the mill would take. This might account for the increased scantlings of the later wide-strip mills and the marked increase of the capacities of the motors for driving them.

Of the schemes proposed by the author, the first resembled, as he himself remarked, one of the earliest of the American wide-strip mills, but with the addition of adequate facilities for handling plates as well as strip. It appeared to be designed for a maximum coil weight of 1000 lb. per ft. of width, or thereabouts, for a finished thickness of 18 gauge.

The second scheme was for wider plates and strips, but subject, apparently, to the same limitation of maximum coil length as the first. The flexibility of the plant, however, seemed to have been sacrificed to some extent on the altar of cost, by the use of one motor for both first and intermediate roughing mills; surely the comparatively small extra cost of separate drives for these two mills would be justifiable.

In neither of these two schemes was there any provision for cutting off the cold front end of the coil before it entered the finishing train.

The third scheme was the most interesting submitted by the author, and compelled comparison, first, with the old Ashland continuous sheet mill with intermediate reheating furnaces, and, secondly, with the Steckel hot mill, which so far did not seem to have found any wide application. Presumably the author had aimed at more effective reheating than was provided by the coil-heating boxes of the Steckel mill, and some further information regarding the furnaces he would use and their working temperatures would be of the greatest interest. In this connection it must be pointed out that the Steckel coilers and decoilers were heated and

inside the furnaces, whereas in this case they would be outside the furnaces. It would seem, however, that the principal loss of heat from the material would be by radiation and convection, and the loss of heat from momentary contact with the coiler rolls small in comparison. A provisional rolling and furnace programme for a given size of strip would be of the greatest interest, together with the probable temperatures at various stages.

AUTHOR'S REPLY.

In replying to the discussion and correspondence on his paper, the AUTHOR desired in the first instance to thank those who had contributed for their constructive comments and appreciative remarks. He was particularly grateful to Mr. Barclay for participating in the discussion and for prefacing his observations with such a kind reference to the assistance which he (the author) had been privileged to afford in the development of the rather unique rolling installation to which Mr. Barclay referred.

The need of adequate reheating facilities was stressed by Mr. Barclay. That was a matter the importance of which it was difficult to over-emphasise, as a great deal of inefficient rolling-mill performance was directly or indirectly traceable to a deficiency in the quantity or quality of the reheating capacity available. In the illustrative examples given in the present paper the primary reheating furnace capacity could be claimed to be calculated upon a very generous basis, to afford an ample time factor together with a small temperature head in the final zone of the furnaces. This would ensure an effective soaking of the material, which was essential for the proper rolling of wide strip stock. Further, a special feature had been made of supplementary or inter-pass reheating designed to give a greater degree of temperature control independent of the final thickness of the product. The problem of reheating ingots for the initial rolling-out into blooms, slabs, and hollows for tubes had been recently dealt with by Krebs [1] in an able paper, which deserved the careful study of those interested on account of the valuable data it contained and the suggestive nature of its author's views.

Mr. Barclay's plea for a closer degree of co-operation between users and builders of plant for the heavy industries in Britain, while perhaps outside the theme of the paper, and therefore not demanding comment here, was so timely and important that it could not be passed over without invoking the warm support of anyone who had the welfare and prestige of British industry at heart. Surely it was evident that our problems in steel or metal manufacturing would be more economically solved as a result of such co-operation, in

[1] W. Krebs, *Stahl und Eisen*, 1934, vol. 54, pp. 101–109, 133–137, 152–158.

conjunction with watchful and unbiased scrutiny of developments abroad, than by the importation of foreign solutions, often without due appreciation of the basic differences existing between our requirements and those for which these were originally conceived.

Mr. Allison's interesting comments seemingly took the author to task for attempting to combine strip with sheet production. This appeared to arise from the fact that, whilst the paper was written primarily from the standpoint of the efficient production of the more ordinary and largely used qualities of sheet and strip, Mr. Allison's approach was from the angle of the producer of those special qualities for which demand must necessarily be restricted and whose character was extraordinarily varied. On this understanding the author would find himself in substantial agreement with Mr. Allison's views, particularly with his advocacy of the medium-sized productive unit as likely to be the most efficient and economic in the long run.

The figure of plant capacity envisaged by Mr. Allison as best suited to conditions obtaining in Britain, *viz.*, 1000–2000 tons per week of, perhaps, 100 operating hours, was substantially lower than that which was tentatively suggested in the paper. Outputs of strip-sheet and slit strip of this order could not be rolled economically on plants of the continuous or even of the semi-continuous types, such as were illustrated in the first and second projects. On the other hand, recourse to the author's hot batch-rolling method would enable a small-capacity plant to be laid down, on the lines hinted at on p. 67 P of the paper, which would, as regards the overall costs attained, compare favourably with those of much greater productive capacity.

Mr. Talbot's reactions to the paper were particularly welcome to the author for the support they lent to his arguments. He was pleased that the scheme forming the second project met with Mr. Talbot's approval on account of the considerable degree of product flexibility which it embodied. He regretted that the time available for the preparation of the paper was insufficient to permit of some consideration of those cold-rolling facilities which, as Mr. Talbot had pointed out, constituted the second phase of the important revolution which had taken place in sheet and wide strip production, and were so essential an accompaniment to any modern scheme for hot-rolling these products.

There were few who could speak with more authority on the subject-matter of the paper than Mr. Kieft, and for this reason the author desired to tender his special thanks for his very valuable and comprehensive contribution. An important part dealt with the repercussions upon the established trade practices in the British sheet and tinplate industry which would ensue from an introduction of strip-sheet methods on an extensive scale. This was an aspect of the problem upon which he (the author) did not feel competent to speak. It would, however, appear desirable for a solution to be

reached whereby it became commercially feasible for a firm to operate a plant catering for both the light-plate and the sheet markets when this combination of products could be so efficiently produced as in the author's first two examples.

Mr. Kieft's proposal for the co-operative installation and operation of a wide-strip mill by an interested trade association would appear to be the most advantageous way of utilising a plant with the American scale of productive capacity. The carriage on the hot-rolled product to the finishing works would be a drawback, and there would be the likelihood of considerable difficulties arising in reconciling the conflicting requirements and divergent interests of the member firms. For these and similar reasons the author favoured putting down plants of smaller capacity whose output could be absorbed in a more closely knit organisation.

The costs for the different processes of sheet and tinplate production given by Mr. Kieft would be most useful as authoritative figures based upon comparable conditions. The statement setting out the advantage in cost of the newer practices over that of ordinary two-high hand mills when producing 20-gauge automobile sheet stock brought out in a striking fashion the savings resulting from the employment of strip-sheet methods.

Mr. Kieft drew attention to the fact that the cost of slab-rolling facilities must be added to the author's estimates in cases where no suitable equipment existed. That was so, as the cost of a slabbing-mill plant was not included in the comparable figure for a large American installation quoted in the footnote to p. 53 P. The author was interested to learn that Mr. Kieft favoured a plant on the lines of the first project, but that he considered an additional finishing stand advantageous. This would undoubtedly be the case when rolling-out was practised, but it was questionable whether it would still be so desirable when reheating could be resorted to, as in this project.

Major Brown's criticisms fell under two heads : First, the width of strip-sheet which the author proposed to roll in his illustrative plants, and, secondly, the anticipated difficulties attaching to the application of the hot batch-rolling method developed in the third project. In arriving at his recommendation of 54 in. as a maximum width of strip-sheet, he (the author) endeavoured to strike a balance between the effect of the growing investment, as the width for which a plant is to cater is increased, with the consequent higher standing charges over its whole production, and the potential utility of the widened range of widths. While there was doubtless a certain demand for sheets 90 in. wide and over from the motor-car body-makers, the author was of opinion that the tonnage of orders available would not yet justify the difference in outlay for a plant capable of rolling these extreme widths. In this connection it should be borne in mind that these extra wide sizes could be produced at a low cost by the cross-rolling of stock rolled in the hot mill in heavy

cold mills of the backed-up type. Until the demand was greater, this method should meet the requirements, especially as sheets of excellent quality resulted.

The manipulative troubles which Major Brown foresaw with the U type of coil-holding furnaces could easily arise with faulty detail in design, but with the experience gathered from the solution of analogous problems the author felt justified in asserting that they were not inherent in the principle. The choice of reheating unit was not, however, restricted to the conveyor type, but, as mentioned on p. 69 P, also embraced furnaces of the ordinary hearth type without mechanism of any kind. The reheating time allowed was a minimum of 20 min. This, with a rolling time per pass (inclusive of handling out of and into the holding furnace) of not more than $1\frac{1}{2}$–3 min., according to the pass, with the moderate-length coils advocated would ensure uniformity of heating. The author did not claim that the direct costs of his schemes would be as low as those of the high-production straight continuous American wide-strip mills, but that the overall costs realised would compare favourably by reason of the appreciably lower standing charges.

He was indebted to Mr. Damiron for so clearly bringing out the importance of aiming at the highest attainable standards of quality when considering plant for strip-sheet production under European conditions. With the trend of the consumer's demand towards ever-increasing quality and uniformity it would be commercially a most unsound policy to entertain any feature which, though cheapening cost either of construction or of production, might hinder the attainment of quality. The projects which he (the author) submitted in the paper were developed with quality of product as a paramount consideration, and the capital costs given were ample to provide every refinement in detail and auxiliary equipment to ensure this desideratum. If a comparison were made between them and the most recent American plants, it would be found that on this score they were by no means inferior, and possibly the facilities for temperature regulation due to the wash-heating or inter-pass heating provisions rendered them superior in regard to metallurgical control.

There was considerable divergence between Mr. Damiron and the author over the question of the value of long coils in strip-sheet production. He was interested in Mr. Damiron's experience in building up heavy coils by welding, as this was at variance with other information in his possession. Doubtless the actual facilities available and the technique employed influenced the cost of the operation, thus giving rise to conflicting opinions as to its economic value. The author had lately been developing the methods of strip-sheet production in the non-ferrous industry. In this line very definite limits were imposed upon the slab weight, so that with increasing widths comparatively short coil lengths were inevitable. Accepting this condition, he had attempted to improve the efficiency

of utilisation of the cold-rolling equipment. As an example of the possibilities in this direction, he might cite the performance of a three-stand tandem mill rolling ½-ton coils up to 26 in. wide. This plant when making a total reduction of 65–70% on stock having a final thickness of about 0·03 in. had an output of 7½–8½ tons per hr. This figure, it was believed, compared favourably on a width basis with what was considered good practice in the United States, employing much heavier coils. It seemed, therefore, to be a question of suitably equipping the cold mills for relatively short coils. That did not appear to present insuperable engineering difficulties. Mr. Damiron also did not refer to the large tonnage of material that most American strip-sheet plants shipped flat.

Amongst other comments on the author's projects, Mr. Damiron was apprehensive that the degree of uniformity of the atmosphere over the hearth of the relatively large wash-heating furnaces required in the first and second projects would not be high enough for good practice. In view of the results given by some recent large plate-normalising furnaces no undue difficulty need be anticipated. He admitted that the maintenance costs on such furnaces might be high, until any weaknesses in the original design were overcome by improvement in detail.

He appreciated Mr. Damiron's interest in the batch hot-rolling scheme exemplified in the third project. In considering the likelihood of appreciable temperature variation in different parts of a coil reheated in the manner proposed, the most important factors to bear in mind were : (1) the amount of temperature rise required in relation to the average temperature of the coil as charged, and (2) the number of laps in the coils. A secondary factor was the nature of the temperature variation in the coils as charged. The amount of the temperature rise was anticipated not to exceed 50° C., and this could be impressed uniformly upon the stock in the time available. The outside and inside laps of coils would tend to be cooler when recharged, and that also compensated in some measure for the difficulty in bringing up the temperature of the central laps.

Some doubt existed in Mr. Damiron's mind as to the suitability of this method when dealing with very small orders. Under such conditions the hearth-type holding furnace would prove more convenient than the conveyor type, owing to the facility with which small lots could be handled and kept track of.

The author was glad that Mr. Morgan concurred in the view that mills of the semi-continuous type were more suitable to British conditions than straight continuous installations. He was pleased to note that, like Mr. Talbot, the plant shown in Fig. 2 appealed to him on account of its flexibility. This would be augmented if, as Mr. Morgan suggested, there was available some ordinary sheet mill capacity for finishing " oddments " orders. The minimum slab thickness which could be dealt with by the wash-heating furnaces in

the first and second projects was $\frac{1}{2}$–$\frac{3}{4}$ in., depending upon the coil weight desired.

He regretted he could not at present furnish any data bearing upon the degree of utilisation of typical American wide-strip mill plants. It was likely that such information would prove distinctly illuminating, especially if presented in chart form, as the author did for other types of mills in his paper on rolling mill flexibility read before the Institute in 1934.

Mr. Morgan's assessment of the advantages and drawbacks of the hot batch-rolling system appeared to be most equitable.

Besides giving much other interesting information, Mr. Smeeton's communication called attention to one of the most important factors bearing upon the cost of production in strip-sheet mills, *viz.*, roll life. That was a point upon which the author did not touch, seeing that the problem was common to both existing plants and those he suggested to meet British conditions. Further, there appeared to be nothing in the latter which might aggravate the severity of the duty to which the rolls were exposed. Nevertheless, he was glad that the roll problem had been mentioned, as it was one which was still far from satisfactory solution.

He was grateful to Mr. Smeeton for pointing out his omission to mention the wide-strip mill plant now under construction at the Dinslaken Works of the Vereinigte Stahlwerke. It was to be hoped that members will be privileged to see this installation during the forthcoming Autumn meeting in Germany. To make the list of such plants complete, mention should be also made of the 66-in. straight continuous plant of American design at the Zaporojstal works in the U.S.S.R.

The economic factors to which Mr. Smeeton drew attention, particularly that of labour displacement, demanded the serious consideration of those embarking upon strip-sheet methods in the flat-products section of the industry.

Mr. Brown stressed the inherently superior quality characteristic of the product of the strip-sheet process, and pointed to the difficulties confronting ordinary sheet mills in approaching the new standard.

The author did not quite see how the operating flexibility of the plant elaborated in the second project would be improved by the employment of separate drives for the first and intermediate roughing stands. Since these must always work together, provided that the speeds of each were correctly selected, there would appear to be no advantage in separate drives sufficient to counterbalance the increased capital cost. Mr. Brown had drawn attention to the omission of crop shears ahead of the continuous finishing trains in the first and second projects. This auxiliary was of undoubted value and should have been included.

One of the author's aims in proposing the hot batch-rolling system was, as Mr. Brown suggested, to obtain more effective re-

heating than was possible with other methods and also a more precise control of the temperature and time factors in such reheating. He did not contemplate the employment of furnace temperatures in excess of 900° C. He agreed with Mr. Brown that the principal heat loss from the stock would occur by radiation and convection, but the decoiling and coiling equipment should be designed to minimise the loss by direct conduction.

In conclusion, he hoped to be allowed to reiterate his thanks to those who had contributed to the discussion and correspondence on the paper, which he felt were of a character fully to justify the hopes entertained in its introductory section. In particular, did he appreciate the constructive criticism of those who had given consideration to the hot batch-rolling method. This would be of much value to the author in its development.

A STUDY OF THE INFLUENCE OF VARYING DEGREES OF COLD-ROLLING AND ANNEALING TEMPERATURES ON THE PROPERTIES OF MILD STEEL SHEETS.*

PART I.—THE INFLUENCE OF COLD-ROLLING AND SUBSEQUENT ANNEALING TEMPERATURES ON THE ERICHSEN VALUES AND CRYSTAL STRUCTURE OF THIN MILD STEEL SHEETS.

By Principal C. A. EDWARDS, D.Sc., F.R.S., D. L. PHILLIPS, M.Sc., and W. H. E. GULLICK, M.Sc. (Swansea).

PART II.—THE EFFECTS OF VARYING DEGREES OF COLD-ROLLING AND ANNEALING TEMPERATURES ON THE PROPERTIES OF MOTOR-CAR BODY SHEETS.

By Principal C. A. EDWARDS, D.Sc., F.R.S., D. L. PHILLIPS, M.Sc., and C. R. PIPE, B.Sc. (Swansea).

Summary.

Part I.—This section deals with a study of the influence of varying amounts of cold-rolling, followed by annealing at different temperatures, upon the Erichsen values and changes in the microstructure of thin mild steel sheets.

Two classes of material have been used for this purpose, one relatively very low in sulphur and phosphorus, and another in which these elements were comparatively high. In each instance one set of experiments was made on material that had been annealed at temperatures below 900° C., prior to cold-rolling, and the other on material in which the preliminary annealing temperature was above 950° C. In this way, it was possible to examine the effects which chemical composition and initial crystal size have upon the critical degree of cold-rolling which produces coarse crystallisation after subsequent annealing.

With very heavy degrees of cold-rolling complete recrystallisation occurs on annealing at temperatures as low as 750° C., irrespective of the initial crystal size. Under these conditions of heavy cold-rolling and low-temperature annealing, better Erichsen values are obtained than by present-day commercial methods, *i.e.*, when the sheets are almost completely hot-rolled to the desired thickness, and annealed in batches at temperatures below 900° C.

Similar results can be obtained by subjecting hot-rolled unannealed sheets to about 10–15% extension by cold-rolling, followed by low-temperature annealing.

Part II.—This section represents an extension of the work done in Part I. to a determination of the influence of cold-rolling and

* Received January 14, 1936.

annealing upon the tensile properties, hardness, and Erichsen values of mild steel sheets, such as are used in motor-car body construction.

This represents a preliminary attempt to correlate the effects of cold-rolling and annealing, the tensile properties, and crystal structure with the Erichsen values, and, further, to ascertain whether the tensile properties obtained after heavy cold-rolling and low-temperature annealing warrant the conclusion formed in Part I., namely, that the drawing properties, after this treatment, should approach those obtained by full annealing.

The evidence seems to indicate clearly that, when complete recrystallisation occurs with low-temperature annealing after heavy cold-rolling, the tensile properties are such as to lead to the view that the drawing qualities of the material should be about the same as those obtained after complete annealing at, say, 950° C.

Unfortunately, it has not yet been possible to demonstrate whether this is the case or not. Before this can be done, it will be necessary to devise a more reliable method than the Erichsen cupping test to determine the drawing quality of sheet material. An attempt is now being made to devise a test for this purpose.

General Introduction.

A study of the influence of varying kinds of mechanical deformation upon the structure and properties of metals and alloys has formed the subject of an extensive number of original publications during the last twenty to thirty years. Special reference has frequently been made to the peculiar sensitivity of metallic crystalline aggregates when they have been subjected to varying degrees of deformation at ordinary temperature and subsequently annealed at varying elevated temperatures.

Many years ago, Howe, Sauveur, and others [1] clearly demonstrated that, under conditions of this kind, there were critical ranges of straining which produced an unusual degree of crystal growth if the metal were afterwards annealed. In those early days, however, the work was mainly of a qualitative character. Perhaps the first serious attempt to place this interesting problem on a quantitative basis was that by Chappell.[2] It was not, however, until the researches of Carpenter and Elam [3] were published that this interesting and important problem was placed on a really quantitative basis, and the essential fundamental factors governing crystal growth of this kind were satisfactorily elucidated. As a result of the work by Carpenter and Elam, metallurgists were enabled to get a correct estimate of the influence of crystal size upon the mechanical properties of aluminium, and for the first time it was possible to study the properties of single crystals of aluminium possessing widely varying orientations.

At a later date, by using the methods that had been worked out by the investigators just mentioned, coupled with some necessary modifications of procedure, Edwards and Pfeil [4] studied the same problem for decarburised mild steel.

It was found, both by Carpenter and Elam and by Edwards and Pfeil, that aluminium, on the one hand, and decarburised mild

steel, on the other, possessed a certain critical sensitivity in regard to straining followed by annealing which would give rise to phenomenally large crystal growth. Strains below this critical degree produced apparently no effect on the ultimate crystal size, whilst strains above this critical value ultimately gave rise to progressively smaller crystals as the initial degree of straining was increased. This has been illustrated by means of a curve which is reproduced in Fig. 1.

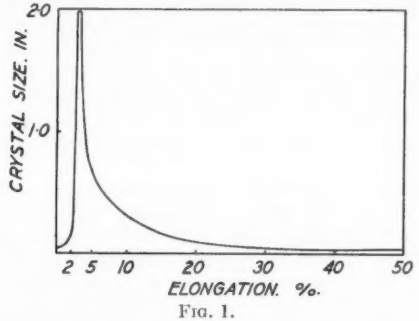


FIG. 1.

From an examination of this curve, it is evident that, with extremely heavy degrees of cold work prior to annealing, the crystals that are finally obtained may be no larger than those in the ordinary annealed or normalised material.

It is, perhaps, rather important, at this stage, to draw attention to one important feature that was revealed by the work of Edwards and Pfeil that was not observed, or was at least not nearly so evident, in connection with the study of aluminium. Thus, for example, in the case of decarburised mild steel it was found that the initial size of crystal, prior to straining, had a marked influence upon the ultimate size of crystals produced after annealing. In other words, the evidence clearly shows that, in order to produce crystals of anything like 2 in. $\times$ 1 in. $\times$ $\frac{1}{8}$ in., it was necessary to start with specimens that contained crystals which closely approximated to a certain critical size. This size corresponded to about 120 crystals per sq. mm. The critical degree of straining required to produce the maximum size of crystal was greater the larger the initial size of the crystal, and, needless to say, it was also greater than was required to produce the maximum size of crystal for material which contained 120 crystals per sq. mm.

Looked at from another angle, this simply means that the larger the initial crystals in the material, the greater is the critical strain required in order to produce the maximum crystal size. And, further, the size of the crystals obtained after straining and annealing is less as the initial crystal size increases.

Some time after the work of Edwards and Pfeil was published, Edwards and Yokoyama [5] studied the effect of varying degrees of straining and annealing upon mild steel. For this work special precautions were taken to avoid, or at least minimise, the loss of carbon during heat treatment. The presence of the carbon introduced another variable factor, and this involved a change in the angle from which crystal growth could be examined. For example, it was found necessary to pay more particular attention to the influence of much lower annealing temperatures and longer times than Edwards and Pfeil used in their work with decarburised mild steel.

The significance of this will be recognised when it is remembered that the presence of the carbon gives rise to the formation of an appreciable amount of γ solid solution at temperatures immediately above Ac_1, and this increases in quantity with further rise of temperature.

The presence of this solid solution interferes with the facility with which crystal growth in the ferrite crystal can take place. Edwards and Yokoyama found that the degree of ferrite crystal growth was affected both by varying annealing temperatures and by the degree of previous straining. In a general kind of way, their results might be summarised as follows : For annealing temperatures of 600° C., the straining that produced the maximum ferrite crystal growth was 8%; for an annealing temperature of 675° C., 6%; 700° C., 5%, and 730° C., 4%. Corresponding values for temperatures above 730° C. could not be obtained, for the simple reason that the presence of the γ solid solution reduced the extent of crystal growth.

In 1927, Edwards and Kuwada [6] studied the influence of varying degrees of cold-rolling upon the Brinell hardness of mild steel, and the effects of different annealing temperatures upon the hardness values of such specimens.

It is unnecessary to go into details of the results obtained; but one or two general observations concerning their conclusions have a bearing upon the work of the present investigation. For example, they found that the greater the degree of cold-rolling, the lower was the subsequent annealing temperature at which this induced hardness could be removed. With cold-rolling to the extent of 40% reduction in thickness, an annealing temperature of 600° C. caused a decrease in the Brinell hardness from nearly 190 to 110, whereas, with material which had been cold-rolled only to the extent of 15%, annealing at the same temperature caused only a small decrease in the Brinell hardness number. Thus, the lower the degree of cold-rolling, the higher is the temperature required to remove its effect, and with very high ranges of cold-rolling comparatively low annealing temperatures are required to produce complete softening. Incidentally, it may also be pointed out that the study of the effects of cold-work upon the crystal structure completely bore out the general

conclusions of Edwards and Pfeil, *viz.*, the more extensive the cold-work, the smaller are the crystals obtained after the material has been annealed, or, in other words, the more complete is the recrystallisation. With something approximating to 40% reduction in thickness, the recrystallisation was so complete as to give rise to a final structure which was comparable with that of the normalised steel.

Now, it is generally known that the tendencies during the last few years, in connection with the manufacture of steel sheets which are to be subsequently used for tinplate making or possibly motor-car body sheets, have been to develop the process of continuous hot-rolling and, after pickling, &c., to finish by continuous cold-rolling operations. The extent of cold-rolling under these conditions is rarely, if ever, less than that which corresponds to a reduction of thickness of 50%, or, say, 100% elongation.

In view of these tendencies, it seemed desirable that a careful study of the influence of varying degrees of cold-rolling and subsequent annealing temperatures upon the mechanical properties and structure of mild steel should be made. Apart from some interesting data by Thomas,[7] the authors know of no published work dealing with this aspect of the subject.

In Part I. of this paper, the thickness of the material examined has been that which corresponds to what is known as " common substance," namely, 0·31 mm. thick, and, apart from a detailed examination of the changes in microstructure, a study of its behaviour after different treatments has been confined to the well-known Erichsen cupping test. This method of testing thin sheets is generally regarded as a useful indication or measure of the relative quality of the material for deep stamping or drawing properties.

In Part II., however, where thicker material has been under consideration, a complete survey of the tensile properties has been undertaken.

In order to give a clear idea of the method of procedure which the authors adopted, to obtain sheets of similar finished thickness but with varying degrees of cold-work in the final stage, it is necessary to give a brief account of the usual method of manufacturing such sheets.

The customary method that is in use in South Wales for making the so-called " common substance " tinplates (*i.e.*, plates of a thickness of 0·31 mm. or 0·013 in.) is as follows: The tinplate bars, having a width of 9–10 in., a length a little greater than the desired finished width of plate, and a weight per foot varying with the desired length of the finished pack, are heated in a reheating furnace to a temperature of about 800° C. For example, in the manufacture of tinplates 28 in. long, 20 in. wide, and 0·013 in. thick, bars 9 in. wide, weighing 21 lb. 6 oz. per ft., are cut to lengths of $20\frac{3}{8}$ in. and heated. They are withdrawn from the furnace in pairs, and are usually given four passes each in a two-high roughing mill in the

direction of the width of the original bar. The result of this operation is to reduce the thickness from about 0·65 in. to about 0·21 in., and to extend the length from 9 in. to 30 in.

At this stage, the sheets are known as " singles." These are heated to the necessary temperature, withdrawn singly, and, by means of two passes, are rolled to about twice their original length (*i.e.*, until they are about 60 in. long and 0·11 in. thick). Each long " single " sheet whilst still hot is folded back on itself, to give two sheets 30 in. long; these are called " doubles." After reheating, the " doubles " are given two passes in the two-high finishing mill, so as to extend them again to double the length and half the thickness. The long " doubles " are folded back on themselves, as in the preceding operation, to produce four sheets 30 in. long and 0·05 in. thick, which are known as " fours." The process is again repeated. Short " fours " are reheated, rolled to a length of 60 in. and a thickness of 0·026 in., and doubled to give a pack of " eight " sheets 30 in. long. The final operation consists of reheating and rolling the short " eights " to the calculated length necessary to yield sheets of the desired thickness, which, in the example quoted, is 59–60 in. The thickness of the finished sheets is 0·013 in., and the length, say, 59½ in., after allowing 3½ in. for waste in shearing to correct size, is sufficient to produce two lots of plates 28 in. long.

For the present investigation, the above method of procedure was modified, in accordance with the following plan : Pieces of mild steel bar of a weight per foot of 21 lb. 6 oz. were rolled to " fours " in the usual way, and, in the " eights " stage, were rolled to different lengths so as to give, after cold-rolling, sheets of equal thickness with varying known amounts of cold-work.

For example, the first pack was completely hot-rolled to full length, namely 59½ in., thus giving the required thickness without any subsequent cold-rolling. The second pack was rolled to 56½ in. (*i.e.*, 5% short of the 59½ in.) so as to allow of a later extension by cold-rolling, corresponding to 5%, and giving, in final form, the desired thickness.

The third pack was hot-rolled to 54 in., necessitating a later extension by cold-rolling of 10%; the others were similarly treated, as indicated below :

Fourth pack hot-rolled to				$49\frac{1}{2}$	in., extended by cold-rolling by				20%.
Fifth	,,	,,	,,	$45\frac{3}{4}$	,,	,,	,,	,,	30%.
Sixth	,,	,,	,,	$42\frac{1}{2}$	,,	,,	,,	,,	40%.
Seventh	,,	,,	,,	$39\frac{3}{4}$	,,	,,	,,	,,	50%.
Eighth	,,	,,	,,	$59\frac{1}{2}$	,,	,,	,,	,,	100%.
				(in fours)					

Each of the above hot-rolled packs was sheared, cut into halves, and opened. Four sheets of uniform thickness were selected from each opened pack, and pot-annealed by the usual commercial method, or normalised, as desired.

These sheets, of varying lengths, were cold-rolled in a two-high

mill, under which conditions the amount of extension produced per pass was approximately 5%. The cold-rolling was continued until each batch of four sheets had attained the desired length necessary to produce 5, 10, 20, 30, 40, 50, and 100% elongation respectively, and the common final thickness of 0·013 in.

PART I.—The Influence of Cold-Rolling and Subsequent Annealing Temperatures on the Erichsen Values and Crystal Structure of Thin Mild Steel Sheets.

Annealing of Test Samples.

Samples of these sheets for the Erichsen test, 3 in. × 3 in., were carefully cut up; four of these specimens for each degree of cold-rolling were used and packed together for each particular annealing temperature, and annealed in batches of sixteen sheets at a time. Thus, for each annealing temperature, samples for all degrees of cold-rolling were annealed at a given temperature in two batches. To protect the specimens from surface oxidation during annealing, they were carefully wrapped up in three sheets of thin sheet steel. With these conditions of wrapping and the necessary foldings there were six layers of sheets covering the samples. After annealing and cooling, it was found that the sheets were only faintly oxidised, giving the well-known oxidation tints. The annealing was carried out in electric muffle furnaces which consisted of silica muffles 9 in. × 4½ in. × 2 in. wound with nichrome resistance wire in outside cases 15½ in. × 12 in. × 10 in., the intermediate space being filled with kieselguhr powder. The method of annealing was as follows: The furnace was heated to the required temperature, and the pack introduced. This caused a drop in the furnace temperature, which was counteracted by using the maximum current until the temperature was within 10–15° of the desired temperature, when the current was reduced so as just to reach and maintain the exact point. The time taken to heat up the pack varied from approximately 3 min. for 500° C. to 12 min. for 950° C.; but, in all cases, the period of heating was timed after the pack had reached the annealing temperature, and not from the time the pack was put in the furnace. Temperatures were measured by chromel-alumel thermocouples, which were calibrated every fortnight against the melting points of pure metals; practically no variation was found. As more than 6000 Erichsen tests have been made, it would be undesirable to tabulate the whole of the results, as this would merely lead to confusion, and since the four results obtained for each degree of cold-rolling and corresponding annealing temperature agreed very closely, the averages only are given in the Tables, and also plotted diagrammatically.

Influence of Heavy Cold-Rolling.

As a first step in the direction of obtaining a clear idea of the problem under consideration, it will be useful to examine the

results obtained by annealing samples at temperatures between 500° and 950° C., which had been previously cold-rolled to the extent of 100% elongation, and compare these with the corresponding data for the same material which had been hot-rolled to the desired thickness. For this purpose, the original bars used were specially made in the laboratory. The composition of the steel was as follows :

Carbon . . .	0·08%	Phosphorus . .	0·014%
Silicon . . .	Nil	Manganese . . .	0·30%
Sulphur . . .	0·02%		

Prior to cold-rolling those sheets that were submitted to this operation, they were normalised in a commercial normalising furnace and, therefore, possessed the usual small-grained equi-axed structure. In both series of experiments the specimens were maintained at the stipulated annealing temperatures for 1 hr. The averages of the results are given in Table I. and Fig. 2. From these curves, it will

TABLE I.—*Erichsen Values and Jenkins Bend Test Values of Hot-Rolled and Cold-Rolled Material.*

Steel cast in bar form.

Sheets As-Rolled, 0·31 mm. thick.				Sheets Normalised and Extended 100% 0·31 mm. thick.			
Re-annealing Temperature. ° C.	Erichsen Value.	Jenkins Bend Test Value.		Re-annealing Temperature. ° C.	Erichsen Value.	Jenkins Bend Test Value.	
		Longitudinal.	Transverse.			Longitudinal.	Transverse.
As-rolled	5·53	16·5	9·5	As-rolled.	4·23	10·0	7·0
500	5·25	18·5	10·2	500	4·55	12·7	9·5
550	5·43	19·7	10·7	550	7·51	16·7	13·7
600	5·72	21·5	10·5	600	8·58	18·7	16·0
650	6·11	21·2	11·0	650	8·64	19·0	16·7
700	7·59	21·2	12·2	700	9·23	19·0	16·0
750	7·55	20·7	13·5	750	9·46	18·2	15·7
800	8·11	20·0	12·7	800	9·15	16·7	14·2
850	8·25	20·2	13·7	850	9·07	15·5	13·2
900	8·10	20·2	12·7	900	9·11	15·5	13·2
950	9·31	18·0	15·5	950	9·56	15·7	15·2

be observed that, in the case of the hot-rolled material, a negligible amount of softening takes place after annealing at temperatures up to 650° C. This is followed by a sharp rise in the Erichsen value at 700° C., after which the improvement is less rapid, until the annealing temperature exceeds 900°, when complete recrystallisation takes place.

With the heavily cold-rolled samples, however, the steel becomes

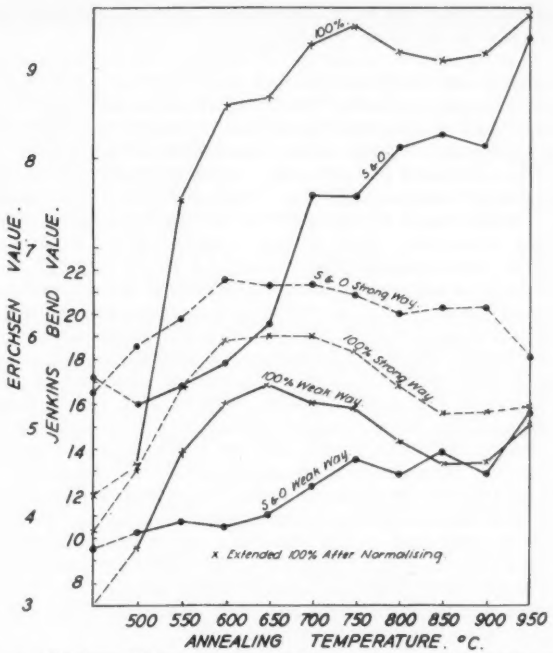

ERICHSEN VALUE.
JENKINS BEND VALUE.
ANNEALING TEMPERATURE. °C.
100%
S & O
S & O Strong Way.
100% Strong Way.
100% Weak Way.
S & O Weak Way.
x Extended 100% After Normalising
500 550 600 650 700 750 800 850 900 950
3 4 5 6 7 8 9
8 10 12 14 16 18 20 22

FIG. 2.—Erichsen Values and Jenkins Bend Values of Sheets 0·31 mm. Thick. (Carbon 0·08%, Phosphorus 0·014%.)

as soft after annealing at 550° as the hot-rolled material is after annealing at 700° C. Further, it will be noticed that this superiority of the cold-rolled samples for any specific annealing temperature is maintained throughout; but, of course, it varies in extent at different stages. It is also interesting to note that :

(*a*) As regards the Erichsen test, the cold-rolled specimens gave better results after annealing at 600° C. and 650° C., than were obtained from those specimens which were only hot-rolled, even when the annealing temperature for the latter had been raised to 900° C.

(*b*) The values obtained by annealing the cold-rolled sheets at 700° C. and 750° C. are as good as were yielded by the hot-rolled specimens after annealing at 950° C.

With regard to the Jenkins alternating bend test, the results of which have been plotted in Fig. 2, it will be seen that :

(i) The effect of the cold-rolling and annealing has been to diminish the values obtained when testing at right angles to the

direction of rolling, but to increase them substantially when testing parallel with the direction of rolling.

(ii) The capacity to withstand alternating bends in the so-called weak way (parallel with the direction of rolling) is as good after cold-rolling and annealing at 600–750° C., as when the hot-rolled material is tested in the same way after any annealing temperature up to 950° C.

The explanation of this rather remarkable influence of the cold-rolling when followed by annealing—more especially by somewhat low annealing temperatures—as compared with the hot-rolled metal, is to be found in the different effects it has upon the final crystalline structure. This is very clearly shown in a selected number of photomicrographs reproduced in Fig. 23 (Plate IV.), which have been taken as typical illustrations of the complete series. The first of the series for the cold-rolled specimens is the structure obtained after annealing at 500° C. This shows the rather heavily deformed ferrite which has undergone no visible change as a result of being heated to 500° C. In the next one, annealed at 550° C., recrystallisation has quite definitely commenced, but is certainly not complete, for the elongated crystals resulting from the cold-rolling can be still clearly seen, and the newly-formed crystals are quite small. Recrystallisation appears to be complete after annealing at 600° C., but many very small ferrite crystals still remain. At all higher temperatures a more regular, equi-axed, though fine, structure is obtained. The structure given after annealing at 850° C. may be taken as typical for all annealing temperatures from 650° C. to just below 900° C. After passing through the A_3 change the character of the structure is not really altered, with the exception that the crystals have become a little larger.

Turning now to the series of structures for the hot-rolled sheets, also given in Fig. 23, the following features may be observed :

In the first case, it will be seen that the structure of the material in the hot-rolled condition, without subsequent annealing, shows the ferrite crystals to be markedly elongated, with dark etching markings which are characteristic of residual hot-rolling stresses. These appearances undergo very little, if any, obvious change by annealing up to temperatures of about 650° C. Above this temperature, however, the ferrite crystals grow, but for the most part they still retain an elongated form until the temperature of Ac_3 has been reached, at which complete recrystallisation occurs.

The outstanding point of difference between the two series of photomicrographs is that, in the hot-rolled material, what can be conveniently described as recrystallisation does not occur at temperatures below the Ac_3 point, whilst after heavy cold-rolling recrystallisation commences at 550° C., and is complete after annealing at any higher temperature. Needless to say, recrystallisation again takes place at the Ac_3 point, but the structure obtained is practically the same as that which results from the recrystallisations by annealing heavily cold-rolled steel at about 700° C.

The Influence of Varying Times of Annealing at Different Temperatures.

The results which have been described above relate only to the effect of annealing at various temperatures for 1 hr. Early in this investigation, however, it was thought desirable to determine what effect, if any, variations in the times of annealing would have upon the structure and properties of the resulting material. With this in view, another series of sheets was rolled with varying degrees of cold-rolling from steel bars having the following composition :

Carbon . . .	0·105%	Phosphorus . .	0·030%
Silicon . . .	Trace	Manganese . . .	0·36%
Sulphur . . .	0·038%		

Samples of all ranges of cold-work were annealed at the usual temperatures for ½ hr., 1 hr., and 5 hr. respectively. Since the outstanding features of the data obtained in this way are so very similar for the various degrees of cold-rolling, it only seems necessary to refer to those obtained for sheets that had been cold-rolled to the extent of 100% elongation. The figures for these are given in Table II. and plotted in Fig. 3.

TABLE II.—*Basic Steel, Box-Annealed before Cold-Rolling.*

Annealing Temperature. ° C.	Erichsen Values. (Average of four tests.)		
	Material Cold-Rolled 100% and Heated for—		
	½ hr.	1 hr.	5 hr.
Not Re-annealed	2·89	2·73	...
500	3·63	3·77	...
550	4·17	5·21	6·51
600	4·78	7·45	7·79
650	7·70	7·77	8·03
700	7·74	7·49	7·42
750	7·63	7·51	7·83
800	7·59	7·52	7·73
850	7·54	7·69	7·83
900	7·73	8·17	8·11
950	8·14	8·06	8·28

From these it will be observed that, in all cases, the Erichsen values show a decided tendency to improve as the annealing temperature is raised above 500° C., and, as might have been anticipated for temperatures between 500° and 650° C., this improvement is greater the longer the time of annealing. This simply means that the recrystallisation of the metal which accompanies the removal of the cold work-hardening takes time, and is more complete for an annealing period of 1 hr. and 5 hr. than for ½ hr. In all probability

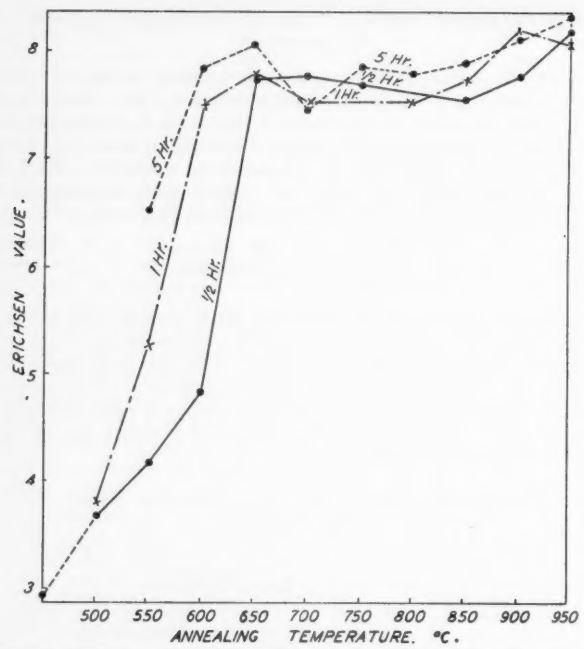


FIG. 3.—Influence of Annealing Time on Basic Deep-Stamping Steel, box-annealed before cold-rolling. Extension 100%.

the degree of softening that occurs at 550° C. might become even more pronounced by a prolongation of the time beyond 5 hr.

At temperatures above 650° C., the differences between the three curves are rather small, consequently it was decided to adopt an annealing period of 1 hr. in subsequent experiments as being a convenient time from which to get a clear indication of the effects of varying annealing temperatures and degrees of cold-rolling. Accordingly, in all later experiments, the period of annealing was 1 hr.

Before proceeding to discuss in detail the experiments which have been made for the purpose of determining the influence of varying degrees of cold-rolling, it should be indicated that it was thought necessary to examine the effects of the original condition of the material as influenced by two different methods of annealing prior to the cold-rolling operation. To emphasise the desirability of doing this, it is only necessary to point out that Edwards and Pfeil found that the effects of different degrees of straining upon the

extent of crystal growth during subsequent annealing depend upon the initial size of the crystals before deformation. The two kinds of annealing which have been taken into consideration in this connection are:

(i) The method of pot-annealing which is still extensively used commercially, and
(ii) Normalising.

In the former, the weight of material in each pot is relatively large, and in consequence a long time is required to reach the annealing temperature and the material has to be maintained above, say, 700° C. for a prolonged period. Further, under normal conditions, the temperature attained is definitely below the A_3 change point; for these reasons the microstructure parallel with the direction of rolling is of an elongated character, the ferrite crystals being some three or four times as long as they are wide. Incidentally, it may also be mentioned that, owing to the longer time the material is at temperatures above, say, 700° C., there are greater opportunities for decarburisation to occur than is the case during normalising. With normalising, the sheets are quite rapidly raised to a temperature of about 950° C., and cooled at a correspondingly quick rate. In this way, complete recrystallisation takes place, and equi-axed crystals of a uniform type and small size are obtained.

Discussion of Results obtained by Pot-Annealing, Cold-Rolling and Subsequent Annealing.

The results for basic steel are given in Table III., and plotted in Fig. 4.

TABLE III.—*Basic Steel, Box-Annealed before Cold-Rolling.*

Material heated for 1 hr. and furnace-cooled.

Annealing Temperature. ° C.	Erichsen Values. (Average of four tests.)								
	Cold-Rolling Elongation—								
	100%.	50%.	40%.	30%.	20%.	10%.	5%.	2·8%.	0%.
Not Re-annealed	2·73	3·38	3·39	3·19	3·60	4·21	4·84	5·21	7·51
500	3·77	4·23	4·52	4·46	4·79	5·69	5·83	6·07	7·43
550	5·21	4·99	5·00	4·97	5·29	5·91	5·99	6·08	7·35
600	7·45	7·31	6·10	5·17	5·49	6·06	6·23	6·52	7·27
650	7·77	7·56	7·30	5·87	5·68	6·28	6·57	6·49	7·47
700	7·49	7·81	7·51	6·57	6·36	6·46	6·59	6·53	7·38
750	7·51	7·70	7·42	6·88	6·18	5·98	6·80	6·74	7·22
800	7·52	7·89	7·47	7·09	6·14	5·70	6·63	6·53	7·20
850	7·69	7·76	7·39	6·80	6·15	5·29	6·71	6·81	6·96
900	8·17	8·12	7·39	6·79	6·45	5·60	6·82	6·73	7·34
950	8·06	8·13	7·94	7·56	7·45	7·87	8·19	7·80	7·61

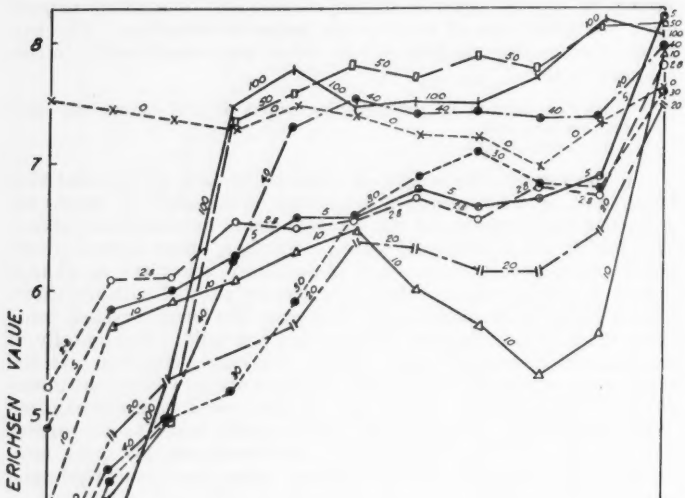


FIG. 4.—Basic Deep-Stamping Steel, box-annealed before cold-rolling.

If one first considers the effects of cold-rolling itself upon the Erichsen values of this steel, it will be observed that rolling which produces an elongation of as low as 2·8% causes a decrease in the value from 7·5 to 5·2 mm. This effect continues, though to a relatively less marked extent, as the degree of cold-rolling is increased, and with 100% elongation the Erichsen value is only 2·8 mm.

When the influence of annealing temperature is generally considered, perhaps the first important and interesting point to be observed is that, with the low amount of 2·8% elongation, the Erichsen values only slowly increase with the annealing temperature to a value of 6·5 mm. for 800° C., and do not rise above that value until the annealing temperature is above 900° C.

This general observation may be said to apply to a slightly varying extent to all degrees of cold-rolling up to 30% elongation, and annealing temperatures below 700° C.

With a previous cold-rolling of 10% elongation, however, and annealing temperatures of 700–900° C., there is a very marked drop in the Erichsen values, and, as will be seen from the microstructures which will be described later, this is due to an excessive degree of ferrite crystal growth which is not removed until an annealing temperature above Ac_3 has been reached, which causes complete recrystallisation. The effects of this tendency for crystal growth can be seen to a lesser degree in the curve for 20% elongation. For still heavier degrees of cold-rolling, however, say, 40%, 50%, and 100% elongation, the character of the curves is different. The heavier cold-rolling causes the material to recrystallise more readily, and this gives rise to a comparatively rapid improvement in Erichsen values as the annealing temperatures are raised from 550° to 650° C., and the effects, in this respect, become greater the more heavily the material has been cold-rolled. This, indeed, is so pronounced that with, say, 50% and 100% elongation, and annealing temperatures of upwards of 650° C., the Erichsen values are quite substantially greater than the corresponding values of the material which has been only slightly cold-rolled.

A further rather important fact which is revealed by these curves should not be overlooked. To emphasise this, it is, perhaps, necessary to point out that, in the present-day method of manufacture of sheets for tinplate making, after the hot-rolling and annealing, the sheets are subjected to three passes in a two-high cold-rolling mill, with the object of producing a burnished or smooth surface prior to tinning, and afterwards these cold-rolled sheets are annealed at a temperature of about 650° C. This cold-rolling produces an elongation of about 2%, and a drop in the Erichsen value, *e.g.*, from 7·5 to 5·2 mm. It will therefore be recognised, by an examination of the data contained in Fig. 4, that with such a low degree of cold-rolling, the effects are by no means completely eliminated by annealing at such a low temperature as 650° C.; indeed, temperatures of 950° C. are required for its complete removal.

It is interesting to observe that the heavily cold-rolled material, after annealing at 650° C., gives values which are, for all practical purposes, equal to those obtained from the very low degrees of cold-rolling after annealing at 950° C.

Looked at from another point of view, it may be said that, with the heavy degree of cold-rolling followed by annealing at 650–700° C., the values are about 15% better than those obtained by annealing the lightly cold-rolled material at the same temperatures.

Microstructures.—The microstructures of representative samples of all the specimens which have been described above have been carefully examined and photographed. These sections were

mounted and polished in such a way as to reveal complete cross-sections of the sheets with the polished surface parallel with the direction of rolling. Owing to the large number of samples involved, it has not been thought necessary or desirable to reproduce all the photographs that have been taken; two series only will be described, namely :

(i) That which was cold-rolled to an extent of 10% elongation.
(ii) That which was cold-rolled to an extent of 100% elongation.

These photomicrographs are shown in Fig. 24 (Plate V.).

With series (i), *i.e.*, 10% elongation, there is not much difference in the structures for all annealing temperatures, say, below 700° C. or, perhaps, 750° C. At higher temperatures—800°, 850°, and 900° C. —pronounced ferrite crystal growth takes place, and it is due to this that the low Erichsen values already referred to are obtained. As would be expected, it will be noted that recrystallisation does not occur until an annealing temperature of 950° C. is reached.

With series (ii), *i.e.*, 100% elongation, the ferrite grains previous to annealing are very much more elongated than in the previous series, and show clear indications of internal deformation in the form of etching strain bands. These elongated crystals undergo little apparent change until the annealing temperature of 600° C. has been reached. At this temperature, however, there are quite definite indications that recrystallisation has set in, with the birth of small crystals. This recrystallisation appears to be complete with an annealing temperature of 650° C., and there is little further change in the structure until a temperature of 900° C. has been reached. At 950° C., the A_3 recrystallisation has taken place, but the change that can be seen, when compared with the structure at 900° C., is not very marked.

TABLE IV.—*Basic Steel, Normalised before Cold-Rolling.*

Material heated for 1 hr. and furnace-cooled.

Annealing Temperature. ° C.	Erichsen Values. (Average of four tests.)								
	Cold-Rolling Elongation—								
	100%.	50%.	40%.	30%.	20%.	10%.	5%.	1·5%.	0%.
Not Re-annealed	3·40	4·55	4·23	4·61	5·30	5·54	5·81	6·75	8·39
500	4·50	5·68	5·20	5·76	5·57	6·61	7·05	7·08	8·10
550	7·29	7·51	6·15	5·98	6·03	6·64	7·13	7·15	7·96
600	8·05	8·02	8·12	7·77	7·52	7·09	6·89	7·05	8·12
650	8·03	7·98	7·96	7·96	7·82	6·55	7·13	7·29	8·10
700	8·07	8·04	8·18	8·47	8·04	7·18	6·59	6·84	8·16
750	8·10	7·83	8·29	8·26	8·06	7·03	6·43	6·94	7·86
800	8·23	8·05	8·00	7·93	8·09	7·55	7·20	7·24	8·28
850	8·43	8·17	8·34	8·13	8·11	7·47	7·48	7·77	8·23
900	8·28	8·43	8·25	8·22	8·12	8·41	8·40	8·06	8·33
950	8·38	8·14	8·33	8·15	8·42	8·00	7·95	8·04	8·16

Influence of Normalising the Steel prior to Cold-Rolling &c., as Compared with Box-Annealing the Steel prior to Cold-Rolling, &c.

For this series of experiments bars of the same material were used and treated in exactly the same way as for the previous series, with the exception that, instead of box-annealing before cold-rolling, the sheets were normalised—*i.e.*, heated to a temperature of 950° C. and moderately quickly cooled, by passing them through a commercial normalising furnace.

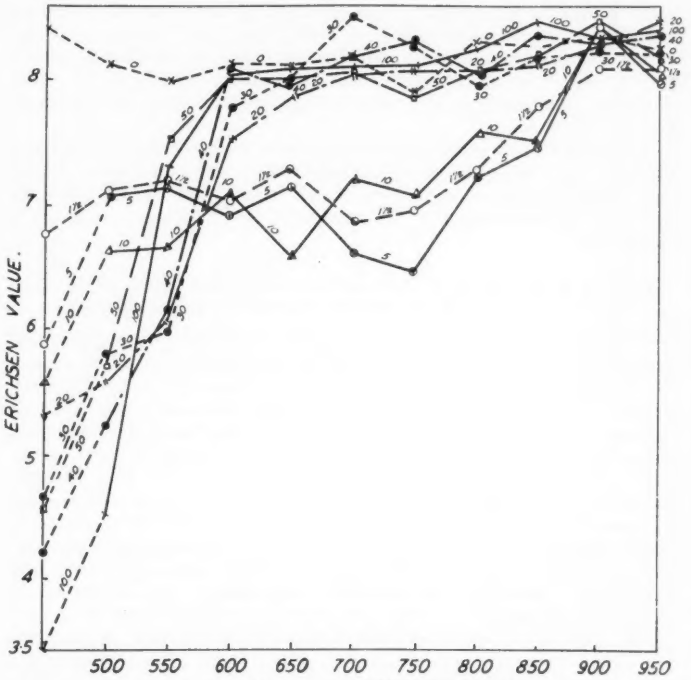


FIG. 5.—Basic Deep-Stamping Steel, normalised before cold-rolling.

The data obtained for this series of experiments are recorded in Table IV., and plotted in Fig. 5. It is scarcely necessary to go into a complete description of these results; all that seems to be required is to draw attention to the more outstanding differences when compared with the former series.

It will be again noted that, with the very low degrees of cold-rolling, *viz.*, $1\frac{1}{2}\%$ elongation, the removal of the cold work is

achieved only after annealing at comparatively high temperatures. The marked drop in Erichsen values observed in box-annealed material for 10% elongation is, in this case, almost completely absent, but it was noticeable for both $1\frac{1}{2}$% and 5% extension prior to annealing. This simply means that the tendency for crystal growth occurs at lower degrees of extension, which is exactly what would be expected when dealing with material containing smaller initial crystals. Further, when dealing with previously normalised material it is of real interest to note that low-temperature recrystallisation and corresponding improvements in Erichsen values occur for all degrees of cold-rolling at and above 20% elongation, the values being very much the same for annealing temperatures above 600° C. in all instances where the elongation exceeds 20%. This is clearly illustrated in the set of photographs which are shown in Fig. 25 (Plate VI.).

A further indication of much the same nature can be seen from the fact that, with the small crystals obtained by normalising, the cold-rolling causes recrystallisation to occur more readily, *i.e.*, at a lower temperature for all ranges of cold-rolling above 20% elongation.

A Study of the Effects of Cold-Rolling Hot-Rolled Sheets which have not been previously subjected to Annealing or Normalising.

For this purpose, material of exactly the same composition, and indeed cut from the same bar-length as that just described, was used.

It is known (*a*) that very heavy cold-rolling causes the Erichsen values obtained after annealing at rather low temperatures to be substantially better than those obtained by annealing the unworked material at the same temperature; and (*b*) that the finishing temperature of hot-rolling such sheets is rather low. It was thought desirable, therefore, to ascertain whether the residual stresses left in the material after hot-rolling when supplemented by a relatively small degree of cold-rolling would give, on subsequent annealing, values which would be comparable with those obtained and previously described by heavily cold-rolling the annealed or normalised material.

In one set of experiments, unannealed hot-rolled sheets were subjected to a 10% elongation by giving them fifteen passes in a two-high mill, and another batch of sheets was given 100% elongation in three passes through a four-high mill at Stolberg in Germany. Corresponding sheets were completely hot-rolled to a thickness of 0·31 mm. Thus, sample sheets all of the same thickness were available after being treated in the following manner :

(i) Completely hot-rolled.
(ii) Hot-rolled to a suitable thickness and then cold-rolled to the finished thickness by means of a 10% elongation.
(iii) Hot-rolled to the appropriate thickness, and then subsequently cold-rolled to the finished thickness by giving them 100% elongation.

The values obtained by annealing the above series are plotted in Fig. 6, and shown in Table V.

From these, it will be noted that the effect of 10% cold-rolling is to cause the material to soften more readily and, in consequence, to give a higher Erichsen value at a lower annealing temperature than was the case for the material that had not been cold-rolled.

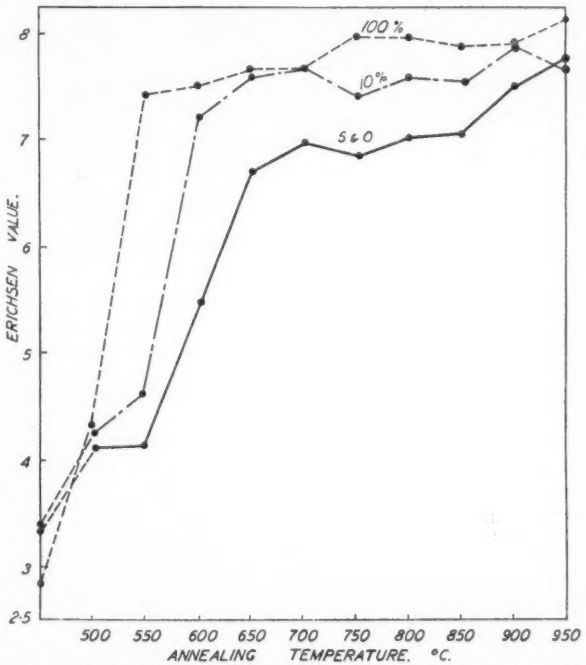


FIG. 6.—Basic Deep-Stamping Steel, cold-rolled in direction of hot-rolling in sheared and opened condition.

Further, it will be observed that, for all temperatures between 600° and 900° C., the cold-rolled material gives substantially higher Erichsen values than that which had not been cold-rolled. The same applies to the series of tests with the sheets cold-rolled to 100% elongation, particularly with regard to the improvement in the Erichsen values at lower ranges of annealing. There is very little difference in the values obtained from the 10% elongation and the 100% elongation, after annealing at temperatures of 650–700° C. From the practical point of view, perhaps the most interesting feature revealed by these experiments is that by giving the steel a

TABLE V.—*Basic Steel, Cold-Rolled without Previous Annealing.*

Material heated for 1 hr. and furnace-cooled.

Annealing Temperature. ° C.	Erichsen Values. (Average of four tests.)		
	Hot-Rolled Sheets.	Hot-Rolled Sheets, Cold-Rolled 10%.	Hot-Rolled Sheets, Cold-Rolled 100%.
Not Re-annealed	3·16	3·34	2·80
500	4·12	4·23	4·34
550	4·13	4·54	7·44
600	5·21	7·18	7·52
650	6·68	7·58	7·69
700	6·97	7·65	7·68
750	6·83	7·38	7·98
800	7·02	7·60	7·98
850	7·05	7·54	7·90
900	7·49	7·87	7·96
950	7·75	7·68	8·14

10% elongation by cold-rolling, without previous annealing, the values obtained by annealing between 650° and 700° C. are extremely good and, indeed, practically equal to those that are obtained by completely annealing or normalising hot-rolled material that has not been subjected to any cold-rolling. From a practical point of view, this seems to suggest that, by a 10% cold-rolling elongation of the unannealed material, *i.e.*, by eliminating the present-day black-annealing operation, the stamping qualities of the material would be equal to those that can be obtained by normalising similar material that has not been cold-rolled, and would be much better than those obtained by present-day methods of procedure. Incidentally, it is of interest to point out that the surface smoothness of the sheets obtained by 10% cold-rolling elongation is much better than is obtained by the present methods of manufacture.

Microstructures.—It is unnecessary to reproduce any of the photomicrographs that were taken from this series because the general features were so similar to those already described. They were in complete conformity with the corresponding changes in the Erichsen values.

Experiments with Acid Steel.

Considering the very wide range in the chemical composition of steel which can be used for the various grades of tinplates, the authors thought it would be useful to examine the effects of cold-rolling, &c., upon acid steel containing higher percentages of sulphur and phosphorus than were present in the material already described.

Whilst open-hearth steel has been used for this purpose, it should be mentioned that any differences in the behaviour of the material

in this connection depend more on the composition than upon the process of manufacture of the steel. In other words, the object in the present instance must not be regarded as an attempt to compare the two processes of steel making, but merely to compare the effects of differences in the sulphur and phosphorus contents of the steels. The composition of the acid steel in question was as follows :

Carbon . . .	0·110%	Phosphorus . .	0·06%
Silicon . . .	0·01%	Manganese . . .	0·45%
Sulphur . . .	0·095%		

The experiments that have been made cover the same range as those discussed for basic steel, *viz.* :

(*a*) Pot-annealed before cold-rolling.
(*b*) Normalised before cold-rolling.

(a) *Acid Steel Pot-Annealed before Cold-Rolling.*

The data for the pot-annealed material are given in Table VI., and plotted in Fig. 7.

TABLE VI.—*Acid Steel, Box-Annealed before Cold-Rolling.*

Annealing Temperature. ° C.	Erichsen Values. (Average of four tests.)								
	Cold-Rolling Elongation—								
	100%.	50%.	40%.	30%.	20%.	10%.	5%.	1·5%.	0%.
Not Re-annealed	2·60	2·73	2·88	2·83	3·23	3·58	3·94	5·30	6·40
500	3·35	3·57	3·95	3·70	4·01	4·40	4·43	5·48	6·42
550	3·53	3·83	4·10	3·96	4·26	4·76	4·82	5·55	6·62
600	5·55	4·33	4·37	4·30	4·50	4·82	5·20	5·91	6·50
650	7·33	6·82	6·73	5·43	4·94	5·15	5·65	5·96	6·15
700	7·40	7·00	7·38	6·83	5·85	5·29	5·58	6·17	6·35
750	7·40	7·10	7·53	6·95	7·04	5·70	5·70	6·15	6·45
800	7·60	7·12	7·40	7·12	7·08	6·06	5·80	6·30	6·58
850	7·85	7·35	7·35	6·85	6·81	6·57	6·16	6·26	6·37
900	7·83	7·72	7·45	7·33	7·00	6·83	6·83	6·74	6·42
950	8·26	8·05	8·01	8·08	8·15	7·94	7·57	7·72	6·70

It is scarcely necessary to give a detailed discussion of these curves. Most of the general features are much the same as those obtained for basic steel. Perhaps the most outstanding difference is that, with this steel, there is no marked drop in the Erichsen values at intermediate annealing temperatures, say, of 750–850° C., even for the low degrees of cold-rolling, such as were so clearly manifest for the 10% cold-rolled basic steel.

Without wishing to be too emphatic concerning the reasons for this difference, the authors think it is due to the amount of carbon that is left in this kind of steel after pot-annealing being larger than

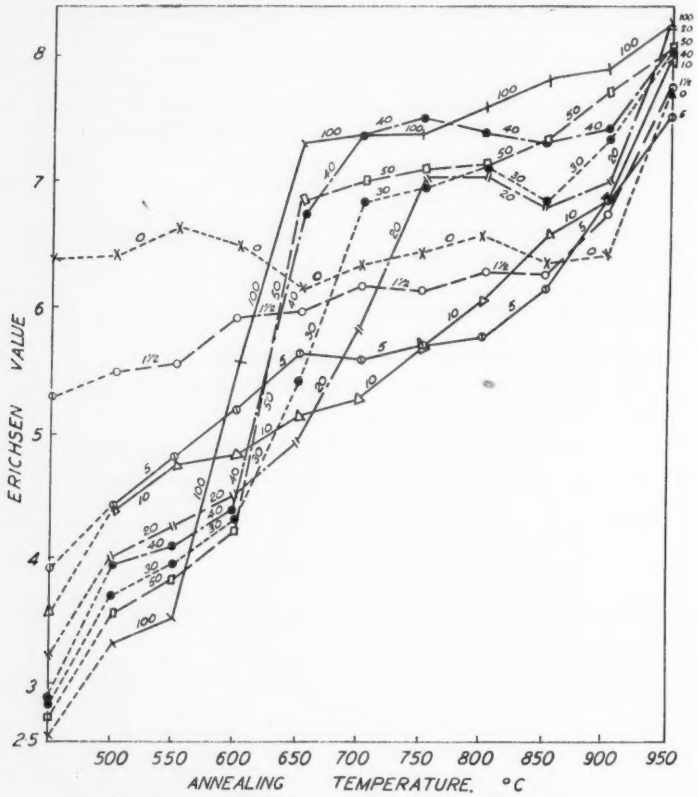


FIG. 7.—Acid Steel, box-annealed before cold-rolling.

is the case in the basic steel, and to the higher percentages of sulphur and phosphorus it contains interfering with the tendency of the ferrite crystals to grow on annealing subsequent to cold-rolling within the lower critical degrees of cold-work. The effects of increasing the amount of cold-rolling from 20% upwards in the direction of facilitating the removal of cold-work by annealing at lower temperatures is the same for this steel as for the basic. In this instance, however, the best values obtained by low-temperature annealing, namely, at 650–750° C., are not as good as for basic steel, and considerably poorer than are obtained by annealing the heavily cold-rolled sheets at 950° C. It is, however, of interest to note that the values obtained by annealing the very heavily cold-rolled sheets

at temperatures of 650–750° C. are nearly as good as those obtained by completely annealing the material that has not been cold-rolled and that which received up to 5% elongation by cold-rolling.

Microstructures.—The structures of the specimens after annealing at all temperatures were examined and photographed, but as these show nothing of outstanding interest or importance, they have not been included in the paper.

(b) *Acid Steel Normalised before Cold-Rolling.*

The data obtained from the samples of acid steel that were normalised before cold-rolling are given in Table VII., and plotted in Fig. 8. On comparing these curves with those of the pot-annealed material, it will be seen that there are very marked differences.

TABLE VII.—*Acid Steel, Normalised before Cold-Rolling.*

Material heated for 1 hr. and furnace-cooled.

Annealing Temperature. ° C.	Erichsen Values. (Average of four tests.)								
	Cold-Rolling Elongation—								
	100%.	50%.	40%.	30%.	20%.	10%.	5%.	1·1%.	0%.
Not Re-annealed	3·02	4·01	4·61	4·61	4·74	5·89	6·04	7·27	7·47
500	4·11	4·79	4·91	5·22	5·38	5·92	6·25	7·39	7·48
550	6·75	5·08	5·10	5·45	5·28	6·42	6·43	7·43	7·74
600	7·45	5·78	5·23	5·83	5·41	6·78	6·63	7·94	7·95
650	7·50	7·90	7·37	7·61	7·10	6·69	6·73	7·80	8·04
700	8·27	8·08	7·99	7·71	7·41	6·58	6·86	7·76	7·69
750	7·92	8·20	7·83	7·95	7·83	6·98	7·21	8·24	7·93
800	7·96	8·31	7·71	8·01	7·59	7·21	7·36	7·98	7·95
850	7·91	7·95	7·73	7·83	7·44	7·44	7·63	7·83	7·91
900	8·17	7·93	7·79	8·21	7·54	7·73	7·74	8·07	7·90
950	8·37	8·23	7·85	8·10	7·94	7·82	7·90	7·95	8·00

This, of course, was the case with the basic material. Speaking generally, the characteristic features of these curves are similar to those obtained for basic steel. Perhaps the only outstanding difference is that the general improvement in the Erichsen values of the less pure acid steel occurs at a somewhat higher temperature than for the basic. The most interesting facts revealed from these experiments are :

(i) By normalising this relatively very impure steel before heavy cold-rolling and low-temperature annealing (650–750° C.) the Erichsen values obtained are equal to those obtained by treating the comparatively pure basic steel in the same manner. This might prove to be of considerable importance to manufacturers.

(ii) By normalising, prior to cold-rolling, and thus obtaining small

equi-axed crystals, the Erichsen values obtained by subsequent annealing at low temperatures are approximately equal to those obtained by completely annealing such sheets, and a little better than are obtained by completely annealing the sheets which have not been cold-rolled, or cold-rolled only to a small extent.

(iii) Another point which might easily be lost sight of, but which

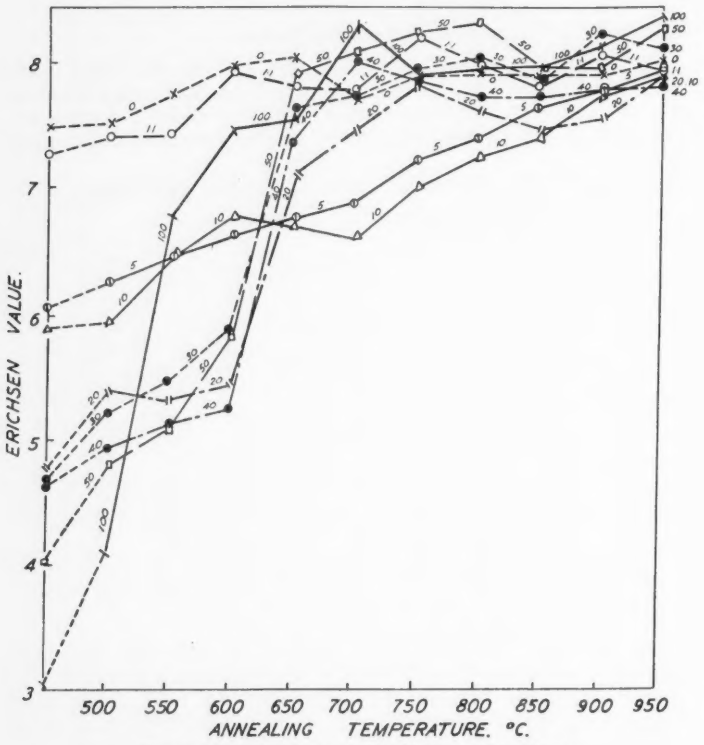


FIG. 8.—Acid Steel, normalised before cold-rolling.

is of considerable practical importance, is that by heavily cold-rolling either pot-annealed or normalised impure acid steel, followed by annealing at comparatively low temperatures, the deep-stamping qualities, as revealed by the Erichsen values, are something like 20% better than are obtained by present-day methods of procedure, even when using steel of the deep-stamping quality as far as chemical composition is concerned.

Microstructures.—The structures of all the specimens were examined, but in view of those which have been previously described, they call for no special comment. Complete recrystallisation on annealing the heavily cold-rolled material occurs at 550° C., and this is followed by slight crystal growth at higher temperatures, and the maintenance of equi-axed ferrite crystals.

Conclusions.

(a) *Basic Steel.*—The most important features of the foregoing investigation may be briefly summarised as follows :

(1) With the basic material that has been box-annealed prior to cold-rolling, there is a critical degree of cold-rolling which produces on annealing at temperatures between 700° and 900° C., an excessive amount of crystal growth, causing the material to give relatively poor deep stamping and drawing qualities, as revealed by the Erichsen test. This is much more pronounced with a degree of cold-rolling corresponding to 10% elongation than in any other instance. This is in general accord with the work done by Carpenter and Elam for aluminium, and by Edwards and Pfeil for iron.

(2) With regard to the influence of the annealing temperature on the removal of cold-work, it has been shown that, for all intermediate and lower degrees of cold-rolling, say, roughly below 30% elongation, there is no specific temperature or narrow temperature range within which the effects of cold-rolling are removed.

In other words, the change is more or less progressive as the temperature is raised, say, up to 700° C. and even higher temperatures, when no ferrite crystal growth takes place. With higher degrees of cold-rolling, however—upwards of 40% elongation, for instance—there is an increasing tendency for softening of the material to take place within a narrow range of temperature lying between 550° and 650° C. The improvement in this connection with samples which had been cold-rolled to the extent of 50–100% elongation is such that the Erichsen values are as good as those obtained from sheets which had not been previously cold-rolled and annealed at 950° C. It should be pointed out, however, that, generally speaking, heavily cold-rolled sheets, after annealing above the A_3 point, give Erichsen values which are rather better than those obtained by annealing such material at 650–750° C.

The foregoing remarks may be stated in another form, *viz.*, the heavily cold-rolled material will give results, on annealing at low temperatures (*i.e.*, 650–750° C.), which are as good as can be obtained by annealing the unworked material at 950° C.; but still better results can be obtained from the heavily cold-rolled material, if the annealing temperature is above 900° C. The authors are unable to say just how much the improvements resulting from cold-rolling and annealing, say, at 950° C., are due to the effect of an improvement in the surface of the sheets.

(3) The results obtained from the basic steel which had been

normalised prior to cold-rolling are, in many ways, different from those derived from the box-annealed material, *e.g.*, there is very little indication of crystal growth on annealing at intermediate temperatures, and this appears in its most intensified form after 5% cold-rolling. Further, the effect of the annealing, which produces small equi-axed crystals, is to intensify the effects of cold-rolling in such a way as to decrease the amount of cold-rolling necessary to produce the maximum softening effects by annealing at low temperatures. In other words, the effect of small initial size of ferrite crystals is to cause the low range of cold-rolling, say, 20–30% elongation, to have approximately the same influence as that of 40–50% elongation on the box-annealed structure.

(4) It is of interest to note that the small initial ferrite grain-size in normalised material also causes the temperature at which softening occurs to be lowered, as compared with that at which softening occurs with the cold-rolled box-annealed steel. This means that a given amount of cold-rolling, when put upon small crystals, has a greater effect than it would have if applied to material having larger crystals, such as are obtained by box-annealing. This is in conformity with what was found by Edwards and Pfeil, namely, that a given degree of deformation produces a greater degree of crystal distortion as the initial size of crystal decreases.

(5) One important practical conclusion to be drawn from the results is that for both box-annealed and normalised basic steel which has been heavily cold-rolled, the results obtained on white-annealing, *i.e.*, at temperatures of 600° C., are almost equal to those obtained by annealing the material above 900° C.; and, of course, are much better than those produced commercially, *i.e.*, by box-annealing, followed by the usual cold-rolling of 2% and subsequent white-annealing.

(b) *Acid Steel.*—The following observations may be made:

(1) The effects of cold-rolling and annealing acid steel containing 0·095% of sulphur, and 0·06% of phosphorus are, in most respects, similar to those referred to in connection with basic steel. There is, however, little or no indication of any particular degree of straining being in any way critical as regards the production of excessive crystal growth on annealing at intermediate temperatures.

(2) From a commercial point of view, it is of interest to note that, with this comparatively impure acid steel, results can be obtained by heavily cold-rolling and subsequent annealing a little above 650° C. which are considerably better than are now obtained by the usual methods of procedure, even from good-quality steel containing low percentages of sulphur and phosphorus.

(3) What has been said in connection with the normalised basic steel applies in almost every detail to the normalised acid steel. It is a remarkable fact that, by normalising this impure steel and subsequently heavily cold-rolling it, the results obtained by annealing at all temperatures above 650° C. are about equal to those obtained

from the basic steel treated in a similar manner. Perhaps the only noteworthy difference that can be observed is that the basic steel seems to show a capacity to soften at a lower temperature than does the acid steel.

PART II.—The Effects of Varying Degrees of Cold-Rolling and Annealing Temperatures on the Properties of Motor-Car Body Sheets.

Introduction.

The experimental data embodied in Part I. of this paper are complete, so far as the effects of varying degrees of cold-rolling and different annealing temperatures upon the Erichsen values are concerned, and it is hoped that the evidence contained therein will prove to be of interest and practical significance to those engaged in the manufacture and use of various kinds of sheet steel.

It is recognised, however, that this information must be regarded merely as a first step in the study of the more extensive problem of the behaviour of such material when it is converted to the wide variety of stampings and pressings that are now required in different industries. One of the chief reasons for this is that the simple, but somewhat arbitrary, Erichsen cupping-test does not involve a true drawing of the material through the jaws of the die, and cannot, therefore, be expected to discriminate satisfactorily between the drawing or pressing qualities of different samples when submitted to these commercial operations. This limitation is, perhaps, more particularly evident when dealing with material which is required to withstand a degree of deformation that closely approximates to its full capacity when in its most suitable condition.

In order to get a still clearer and more quantitative idea of the influence of varying degrees of cold-rolling and subsequent annealing temperatures upon the drawing qualities of mild steel sheets, the next step appeared to be to make a careful examination of the influence of these treatments upon the tensile properties.

This might then be followed by an attempt to correlate the tensile properties and treatment with the behaviour of the steel when it is being shaped into pressings.

In this way, one might hope to obtain a more trustworthy conception than is now possessed concerning the special property, or the manner in which a combination of properties react upon each other, and determine the ability of a given steel to be successfully formed into a difficult pressing. Once this is done, it should then be possible to devise a simple method of testing the quality of sheets for pressing operations, which would be acceptable to both manufacturers and users. Incidentally, by proceeding in this manner, one ought to be in a better position to gauge more precisely

the relative advantages of different degrees of cold-rolling and varying annealing temperatures.

In planning the present investigation, it was decided to use thicker sheets than "common tinplate substance" as used in Part I. The reasons for this departure were as follows:

(i) The experimental difficulties and errors were diminished.
(ii) The evidence obtained could be used for tinplate considerations and be directly applicable to the motor-car and steel furniture industries.

The need for work of this kind has become more urgent, owing to the rapid development of cold-pressing and drawing as a means of fabrication in recent years, which has acted as a stimulus to the steel sheet trades. Then, again, during the last ten years, new methods of rolling sheets have been introduced which involve heavy cold-rolling, and, in consequence, it has become a matter of real importance that one should have an accurate picture of the effects of this treatment, coupled with that of varying annealing temperatures.

In the motor-car industry, the introduction of cellulose lacquer painting and quantity or mass production has created a demand for sheets possessing almost flawless surfaces and with physical properties, such as ductility and toughness, that will permit of maximum drawability with a minimum amount of intermediate annealing.

This need for a high-quality product has been intensified by a reduction in the number of total pressings making a motor-car body, and by a call for sheets of as light a gauge as possible, while still possessing maximum ductility, so as to reduce the weight of the body and improve the power-to-weight ratio.

When it is remembered that the two factors of paramount importance in high-grade sheets are surface quality and physical properties, it is not surprising that so much money has been spent, particularly in America, in an endeavour to supply a product possessing these properties in a high degree. Rolling methods of long standing have been improved by careful attention to details, and more modern plant and new methods have been introduced which are claimed to supply a far better product than that obtained by the older methods of processing. The new methods have, in the main, centred around (*a*) the introduction of continuous normalising or single-sheet annealing furnaces in which every individual sheet is annealed above the upper critical point, and, as a result, possesses more uniform properties than those given by a box-annealing treatment only, and (*b*) a reduction in the amount of hot-rolling, in favour of an increased amount of cold-rolling, followed by low-temperature annealing, with a resulting improvement in the surface quality of the sheets. This latter has been applied both to sheet-rolling and to strip-rolling, but with the same object in both cases, namely, an improvement in the quality of their respective products.

While the technical literature contains a very large number of

papers relating to the methods of manufacture and types of plant used for the production of mild steel sheets and strip for deep-drawing purposes (excellent bibliographies are given by Lawrence [8] and Mort [9]), there is little information available concerning the tensile properties of mild steel sheets manufactured by these various methods.

Swinden and Bolsover [10] describe experiments on cold-rolled strip steel. The first section contains a record of their experiments on the effect of progressive cold-working in relation to some tensile properties of four steels of different carbon contents. The composition of one of their steels is such as would be used for deep drawing (carbon 0·10%, manganese 0·41%). This material, after hot-rolling, was cold-rolled to an extent from 0 to 66% reduction in thickness. Their curves show that the maximum stress and proof stress increase somewhat sharply for the first 10% reduction in thickness, thereafter increasing uniformly with the degree of cold-rolling. The percentage elongation falls rapidly in the initial stages of cold working, but for reductions greater than 10% it falls almost in a linear manner.

In Section II. of the paper by Swinden and Bolsover, they give results of annealing experiments made on the cold-rolled materials. Referring again to their mild steel with 0·10% of carbon, the curves for reductions of 35% and 66% show, in the main, a gradual decrease in maximum stress and proof stress, and a gradual increase in elongation with annealing temperatures up to 500° C. At 600° C. there is a sharp drop in the maximum stress and proof stress and a marked increase in the elongation values.

In a paper by Thomas [7] (already referred to) experiments are described which were made primarily to determine what ranges of cold-rolling and annealing temperatures give rise to excessive grain-size in mild steel sheets. His results, measured in terms of the Erichsen ductility and Jenkins bend tests, show that from 7½% to 20% reduction in thickness by cold-rolling, followed by box-annealing at temperatures between 700° and 900° C., may give rise to coarse crystallisation, with or without decrease in cupping and bend values.

It is of interest to note, at this stage, that during the past few years an increasing amount of attention has been given to the scientific study of cold drawing and pressing operations. This is shown by the fact that a joint meeting of some twelve scientific societies took place a short time ago to consider the subject in some detail.[11]

In view of the paucity of information relating to the properties of cold-rolled and annealed sheets, the work which will be described in this section of the paper was undertaken. This covered a study of the influence of different amounts of cold-rolling and subsequent annealing upon the physical properties of mild steel sheets of 20 gauge (0·035 in.) thickness.

Method of Testing.

Selection of Material.—The steel used in this research was selected as being typical of that used in the manufacture of full-finished deep-drawing sheets. It was a basic mild steel of the following composition :

Carbon . . .	0·062%	Phosphorus . .	0·010%
Manganese . .	0·28%	Silicon . . .	Trace
Sulphur . . .	0·025%		

In order that variations in composition, due to heterogeneity, should be as small as possible, a bar was selected from the middle portion of the rolled ingot, and of a length sufficient to supply ten multiples, each 27½ in. long, for subsequent hot- and cold-rolling into sheets 72 in. long, 27 in. wide, and 0·035 in. thick.

The first multiple was hot-rolled to the finished length of 72 in. in doubles. The remaining multiples were hot-rolled to lengths such that, after the required predetermined extensions by cold-rolling had been given, all the sheets were of a common length of 72 in. and 0·035 in. thick. The cold-rolling extensions decided upon were 0%, 5%, 10%, 15%, 20%, 40%, and 100%. The procedure was as follows : The multiples were hot-rolled to the required lengths in doubles, and the packs of two " square sheared " to remove rough edges. One sheet from each pack was normalised in a continuous gas-fired normalising furnace, and the other given a box-annealing treatment, together with other material, at some temperature between 700° and 800° C. Annealing at temperatures in excess of about 850° C. is commercially impracticable in the deep pots as used at present, owing to the tendency for welding or sticking to take place. This occurs more readily when the carbon, sulphur, phosphorus, and silicon contents are low, as in the steel used in this research.

After normalising or box-annealing respectively, both sheets were pickled in hot dilute sulphuric acid in a pickling machine, scrubbed, washed and dried, and then cold-rolled to the required degree in a two-high cold-rolling mill. The number of passes required in cold-rolling varied both with the amount of extension, and also with the condition of the sheets prior to rolling; for the lower degrees, say 5% extension in length, one or two passes were sufficient, but for the higher degrees, such as the 100% extension, as many as sixteen passes were required. The initial passes gave a fairly high extension, but this decreased with each pass after, say, the fourth. For the same degree of extension, it was found that the material which had been box-annealed required a smaller number of passes than that which had been normalised.

Preparation of Test-Pieces.—In addition to the determination of the tensile properties with which this work is mainly concerned, it was decided to carry out cupping and hardness tests on the cold-rolled and annealed material. The Erichsen machine was used for

the cupping tests, and the Rockwell and Herbert dead load machines for the Rockwell and Brinell hardness tests respectively. Both the cupping and hardness tests were conveniently made on the same specimen, namely, the standard Erichsen test-piece, which is 3 in. square. Test-pieces were cut from all the sheets, so as to be thoroughly representative of the whole of the sheet area.

In the preparation of the tensile test specimens, a somewhat more complicated procedure was necessary. In view of the large number of test-pieces required, it was necessary to adopt a simple method of preparation. With this in view, they were obtained by stamping them from the cold-rolled sheet. For this purpose, hardened steel blanking dies were employed, so designed that they would produce specimens of the following dimensions :

Total length	14	in.
Length of parallel section	9·5	,,
Width	0·812	,, (Approx. $\frac{13}{16}$ in.)
Length of shoulder	2	,,
Width of shoulder	1	,,
Radius at shoulder	$\frac{7}{8}$	,,
Gauge length	8	,,

The width of the parallel section was approximately $\frac{1}{16}$ in. greater than that required in the test-piece in its final form. The test-piece, after blanking, was tightly clamped between the two plates of a hardened steel templet with the same dimensions as above, excepting that the parallel section was $\frac{3}{4}$ in. wide. The templet was held in a vice, and, by means of very careful filing with a medium file, the extra $\frac{1}{16}$ in. (*i.e.*, $\frac{1}{32}$ in. on each edge) was removed. The object of this operation was to remove that portion of the test-piece which had been work-hardened by the shearing action of the blanking tool and which, if not removed, would affect the results obtained in subsequent testing. In some preliminary tests it was found that there were small, but important, variations in the thickness of some of the test-pieces from shoulder to shoulder measured along the axis. The maximum variation encountered was 0·003 in. (0·033 in. to 0·036 in. actual thickness). In a sheet steel test-piece, where the ratio width/thickness is high, a difference in thickness of this magnitude has an appreciable effect on the cross-sectional area.

A simple calculation shows that $\pm$ 0·001 in. in thickness is equivalent to 0·020 in. in the width to give the same cross-sectional area. The result is that, with a constant width and a variation in thickness, the specimen tends to fracture at the zone of least cross-sectional area, which in most cases occurs near a shoulder, outside, or only just inside the gauge length. Under these conditions, the figure obtained for total percentage elongation would be on the low side. Corrections were made for variations in thickness in the following manner : Three measurements of thicknesses were made on each test-piece, near the shoulders, and at the centre of the parallel portion. In those specimens showing a variation, an

equivalent amount of metal, on the basis of the calculation referred to above, was removed by means of a smooth file from the edges of the test-piece at the zone of greatest thickness, such that, although the *thickness* might vary along the length of the specimen, the *cross-sectional area* was made constant. By employing this method, the majority of the test-pieces fractured within the central 4 in. of the gauge length, the exceptions, in the main, being due to surface flaws which opened out during pulling.

Experimental Procedure.—Test-pieces were prepared, taken both parallel to and at right angles to the direction of rolling of the sheets, for each annealing temperature (in steps of 50° C. from 500° C. to 950° C.). Three longitudinal and three transverse specimens from both the normalised and box-annealed sheets, making twelve in all, were wrapped in three small sheets of thin sheet steel (untinned), giving actually nine thicknesses of thin sheet around each set of test-pieces. This was considered an essential precaution to minimise external oxidation and decarburisation. The pack was then annealed *at* the required temperature for 1 hr., the heating current was then switched off, and the pack was allowed to cool in the furnace overnight. The Erichsen test-pieces were treated in a similar manner, twelve specimens 3 in. square being annealed together for 1 hr. and cooled in the furnace.

Tensile Testing.—The tensile tests were carried out in a 10-ton Buckton machine, operated by hand. Values were obtained for the limit of proportionality, yield point, ultimate strength, and elongation on 8 in. and on 2 in., including fracture. The determination of the limit of proportionality was made by means of the Cambridge vibrating tongue extensometer.

The thickness of the test-pieces employed was not great enough to allow the extensometer points to grip the specimen. To overcome this difficulty, two small collars of mild steel were made to fit over the test-piece and clamped rigidly to it, by means of two small screws. The four points of the extensometer gripped the two collars. The effect of the elastic extension of the specimen was transmitted through the collars to the instrument and measured in the usual way. While the use of collars would not be considered admissible for accurate determinations of the modulus of elasticity, it was felt that their use was justified for comparing the limits of proportionality obtained in the cold-rolled and annealed specimens tested for this work.

General Observations.

In order that the possible cause, or causes, of some of the outstanding differences in the tensile properties which are to be discussed may be more readily understood, the authors feel it will prove useful, at this stage, to refer to certain relevant theoretical considerations, as well as to some facts which should be kept in mind.

One important factor to remember, in dealing with an investi-

gation of this kind, is that the initial size of the crystals in the material prior to cold-rolling and later annealing, may be expected to have an effect upon the final tensile properties. In this connection, the conclusions Edwards and Pfeil [4] drew from their work on the production of large crystals in iron may first be cited, and the significance of these in connection with the present investigation may then be indicated. They said :

" (i) The critical strain required to produce very large crystal growth on subsequent annealing varies with the initial grain-size of the material used. This variation is in the direction of a greater strain being needed as the grain-size increases. With very large crystals sufficient strain to cause growth cannot be applied, owing to recrystallisation occurring at the crystal boundaries.

" (ii) Surface crystals of the original finely crystalline aggregate behave differently from interior ones, requiring a greater tensile strain before they will disappear.

" The following explanation is offered to assist in accounting for, and in connecting together, these two facts :

" During the deformation of an isolated crystal there is but little change in the internal arrangement of the crystal. Some change must occur, for it has been shown that single-crystal tungsten filaments harden by cold-work. A hardening was also found by the authors when large iron crystals were cold-worked. In the case of single iron crystals, however, whatever change occurs up to 25% elongation, is removed on annealing, without being accompanied by recrystallisation. Nor does recrystallisation set in if the temperature be raised to just below Ac_3. In the case of a single crystal it is considered that deformation occurs by a process of slip, causing little change in the crystal lattice. If, however, two crystals in contact are deformed, interference with slip will occur, owing to the change in the direction of the slip planes in passing from one crystal to the other. Under these circumstances, some other kind of movement occurs during deformation; this second kind of movement will be most intense at and near the crystal boundaries, and less so as the distance from the boundaries increases.

" X-ray analysis does not indicate any difference between the lattice constants of cold-worked and of annealed metals, but shows a relation in the former between the directions of the crystallographic axes and the direction of straining. The second type of deformation, caused by interference with slip, is interpreted, therefore, as a rotation of the crystallographic axes accompanied by elastic strain, the latter not being detected by X-ray analysis. The depth to which this change penetrates from the boundaries depends upon the degree of deformation. With small crystals but little deformation will cause the depth to correspond with the radius of the crystals. The larger the crystals, the greater will be the deformation necessary to cause the change to reach the centres of the crystals.

" When this second type of deformation has penetrated to the

crystal centres, and the strain at the crystal boundaries has not exceeded a certain value, the authors consider that the degree of axial alignment due to rotation has proceeded to such an extent that, on annealing, it is more easy for the atoms to form a single crystal than to revert to their original orientations.

" With very large crystals, however, before the second type of deformation has penetrated to the centres, the strain set up at and near the crystal boundaries has become so great that, on annealing, it is more easy for the atoms in these highly strained regions to form new crystals, *i.e.*, recrystallise, than for a process of perfectly uniform and stable alignment to occur."

It must necessarily follow, from the foregoing :

(*a*) That a given amount of deformation must produce a diminishing degree of strain-hardening as the initial size of the crystals in the specimen increases; and

(*b*) Since the facility with which low-temperature recrystallisation occurs and the extent to which it takes place, as defined by the number of crystals per unit area, increase with the degree of strain-hardening prior to annealing, it follows that the original size of the crystals in the material, before cold-rolling, will have some influence upon the tensile properties after annealing. Stated qualitatively, the effects in this connection will be : The larger the initial crystals, the greater the amount of straining (cold-rolling) required to produce any desired crystal size in the finished sheet.

It was for these reasons that it was decided to carry out two series of experiments, namely, one for which the material had been normalised after hot-rolling, but previous to being subjected to any cold-rolling, and another for which the preliminary heat treatment consisted of what is known as pot-annealing.

In the former, the conditions of heating and cooling are sufficiently under control to produce regularly a small and uniform size of crystal when different pieces of steel of a given composition are treated at different times. A typical structure, after normalising, of a specimen used in this investigation is illustrated in Fig. 27 (Plate VII.).

With regard to pot-annealing, however, the conditions are such as to make it difficult definitely to ensure that the material from day to day becomes heated to the same temperature, &c. In view of this, and the fact that it was practically impossible for the authors to arrange to have all their samples annealed in a single pot at the same time, some variation in the initial size of crystals contained in the different samples of this series was inevitable. In only one instance, however, namely, the sample cold-rolled to the extent of 10% elongation, was this very marked, but in this example the crystals were substantially larger than for the other cases. The authors feel that this cannot be entirely attributed to the annealing, but that in all probability it is due to the finishing temperature during hot-rolling having been such as to leave in the material a critical degree of rolling stresses, thus rendering it sensitive to crystal growth when annealed below 900° C.

HOT-ROLLED SHEETS

SHEETS HOT-ROLLED AND NORMALISED BEFORE COLD-ROLLING. 100% EXTENSION

Re-annealing Temperature

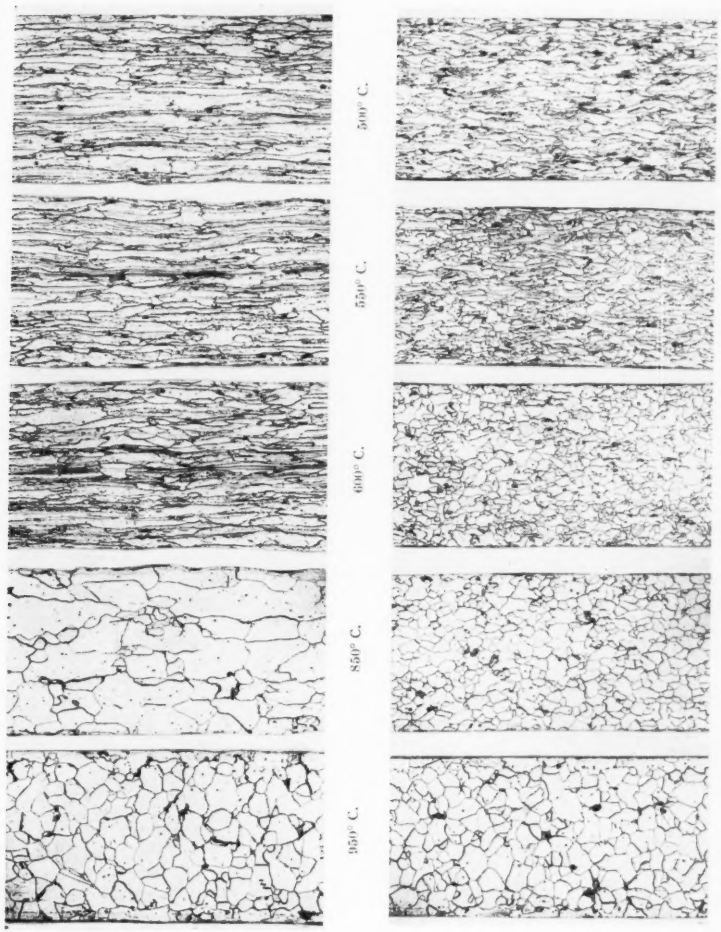


FIG. 23.—Effect of re-annealing hot-rolled, and normalised and heavily cold-rolled sheets. Steel cast in bar form. × 150.

(Micrographs reduced to half-size linear in reproduction.)

[*Edwards and others.*

[*To face p.* 128 P.

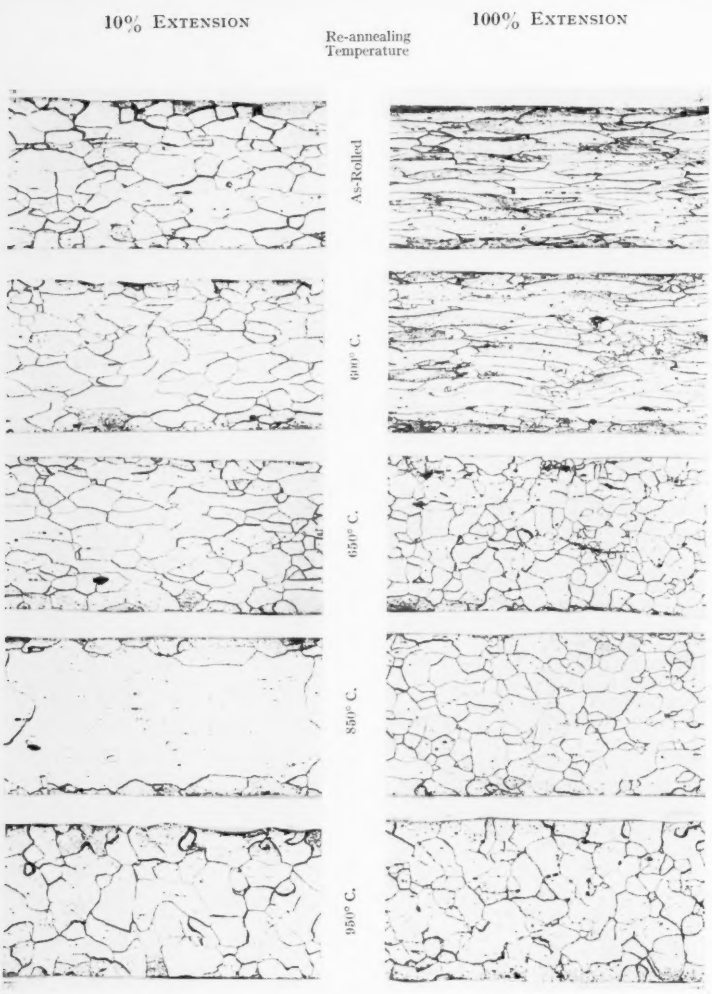


FIG. 24.—Effect of re-annealing on commercial basic deep-stamping steel box-annealed before cold-rolling. × 150.

(Micrographs reduced to half-size linear in reproduction.)

[*Edwards and others.*

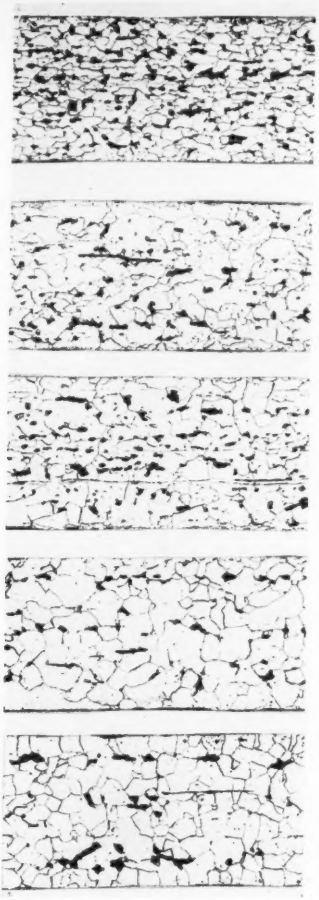


FIG. 25.—Effect of re-annealing on commercial basic deep-stamping steel normalised before cold-rolling (20% extension). × 150.

(Fig. 25 reduced to half-size, and Fig. 26 to two-thirds linear in reproduction.)

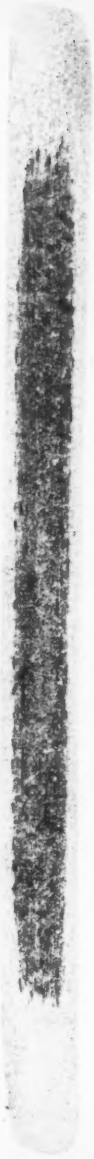
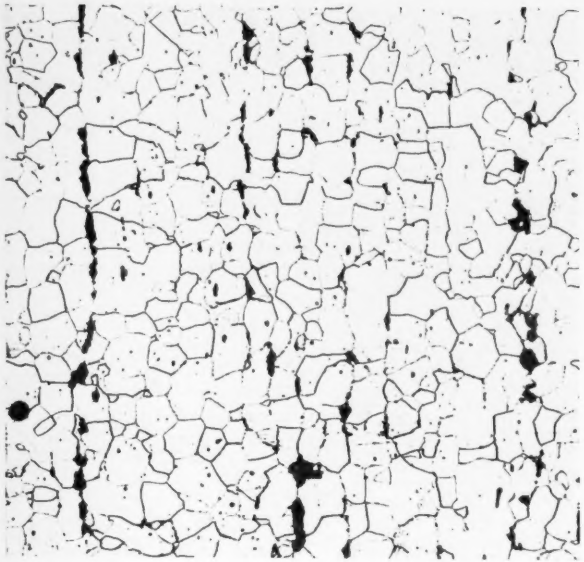


FIG. 26.—Sulphur print of sheet bar.
[*Edwards and others.*

RE-ANNEALED AT 950° C.



NORMALISED

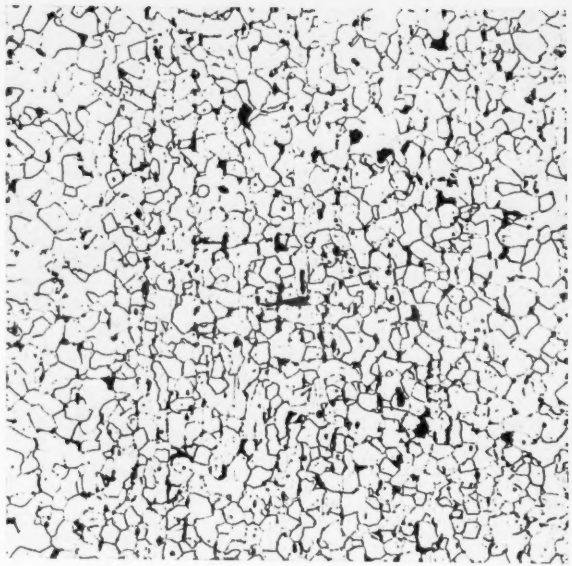


FIG. 27.—Steel hot-rolled and re-annealed at 950° C., or hot-rolled and normalised. × 100.

[*Edwards and others.*

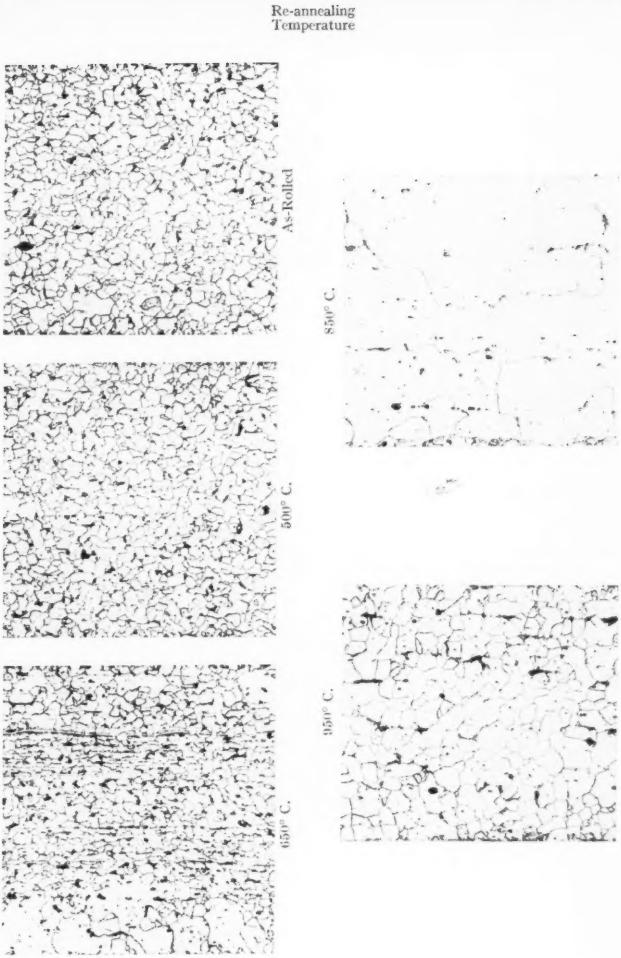


FIG. 28.—Effect of re-annealing on normalised and lightly cold-rolled specimens (5% extension). × 100.

(Micrographs reduced to half-size linear in reproduction.)

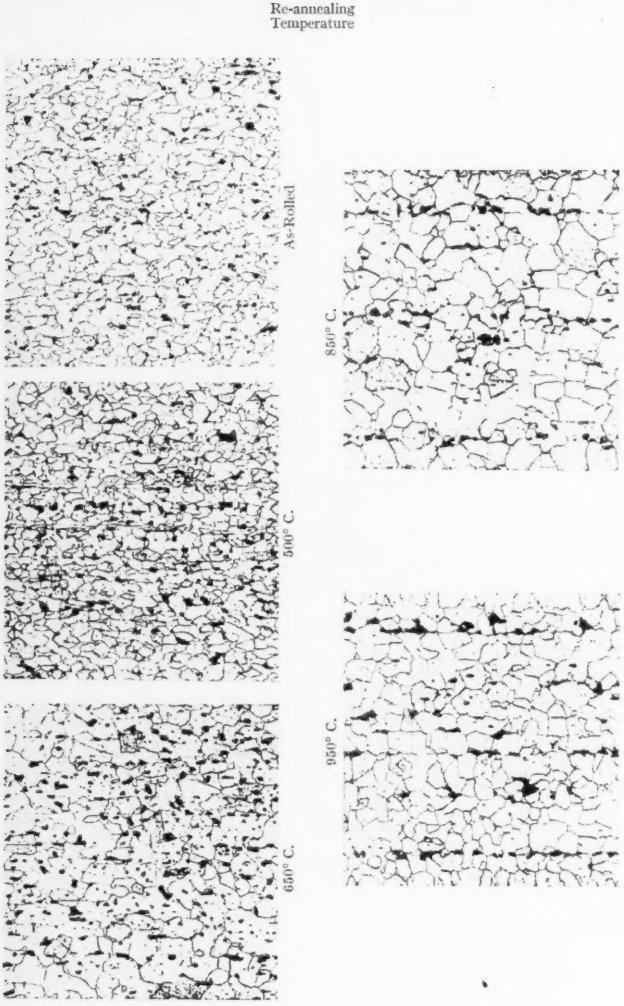


FIG. 29.—Effect of re-annealing on normalised and moderately cold-rolled specimens (20% extension). × 100.

(Micrographs reduced to half-size linear in reproduction.)

[*Edwards and others.*

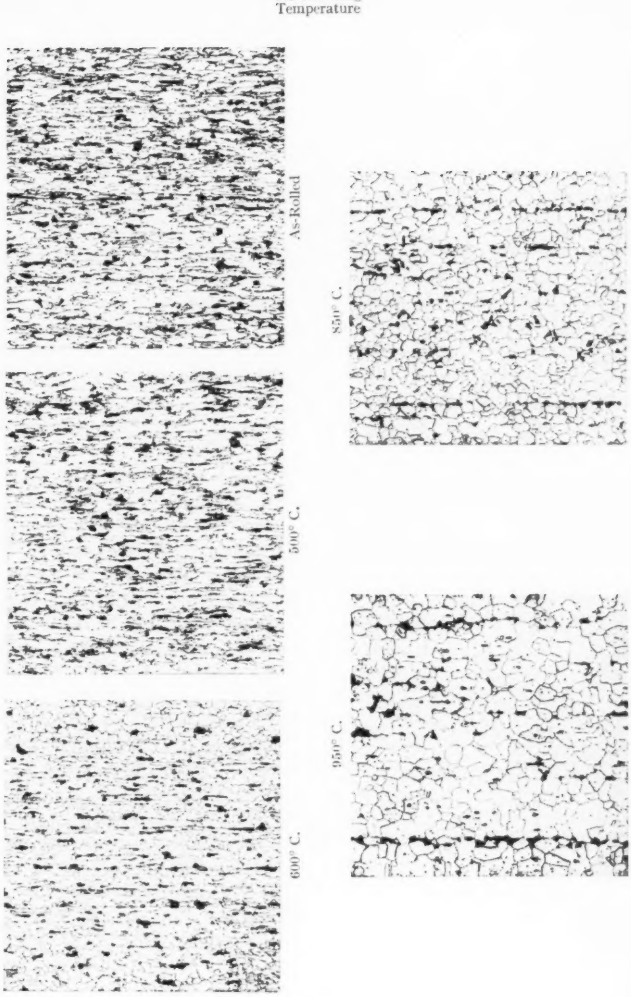


FIG. 30.—Effect of re-annealing on normalised and heavily cold-rolled specimens (100% extension). × 100

(Micrographs reduced to half-size linear in reproduction.)

[*Edwards and others.*

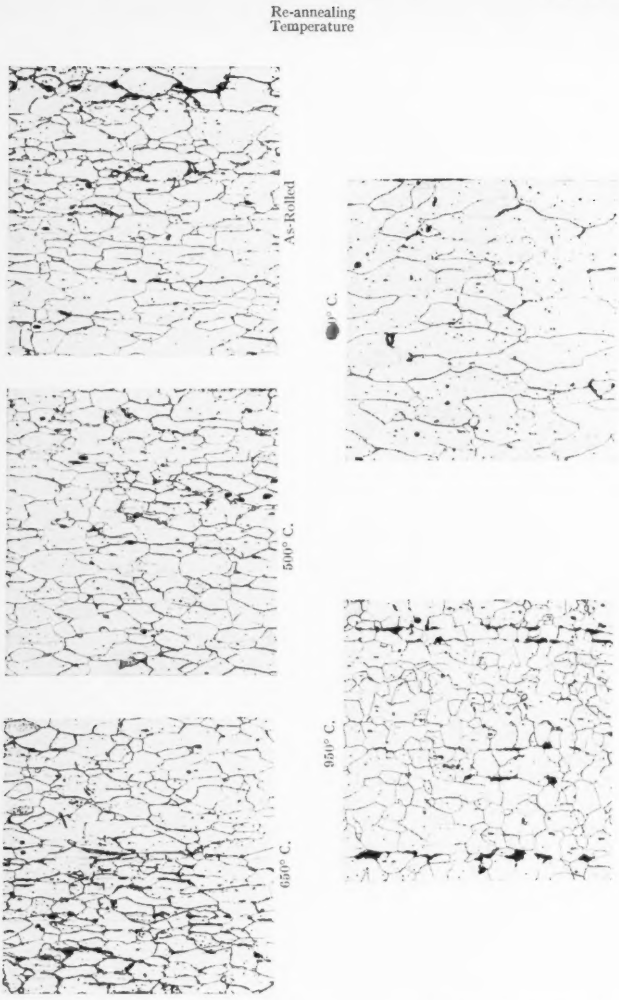


FIG. 31.—Effect of re-annealing on box-annealed and lightly cold-rolled specimens (5% extension). × 100.

(Micrographs reduced to half-size linear in reproduction.)

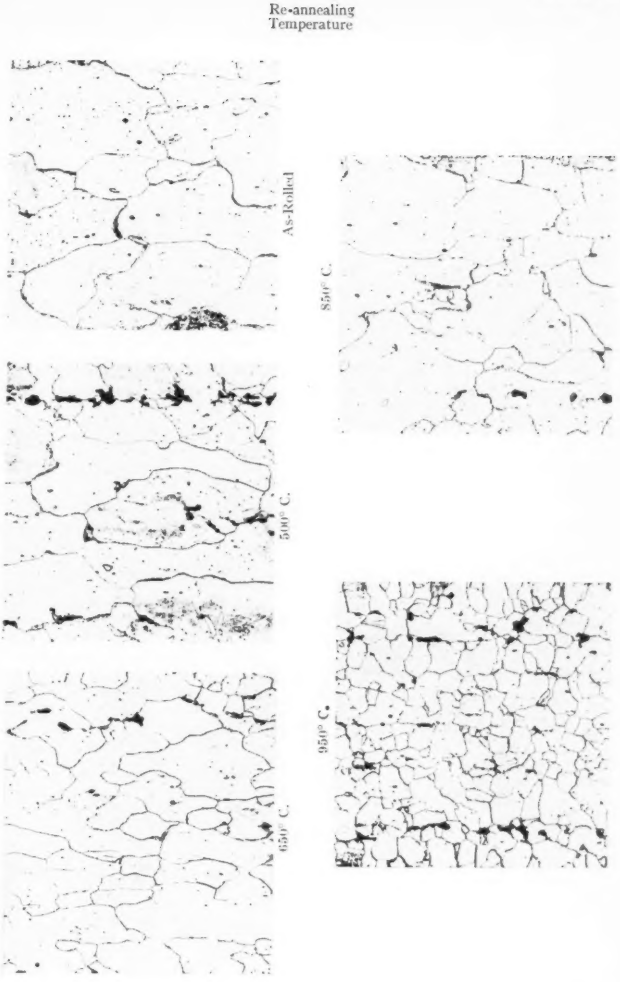


FIG. 32.—Effect of re-annealing on box-annealed and moderately cold-rolled specimens (10% extension). × 100.

(Micrographs reduced to half-size linear in reproduction.)

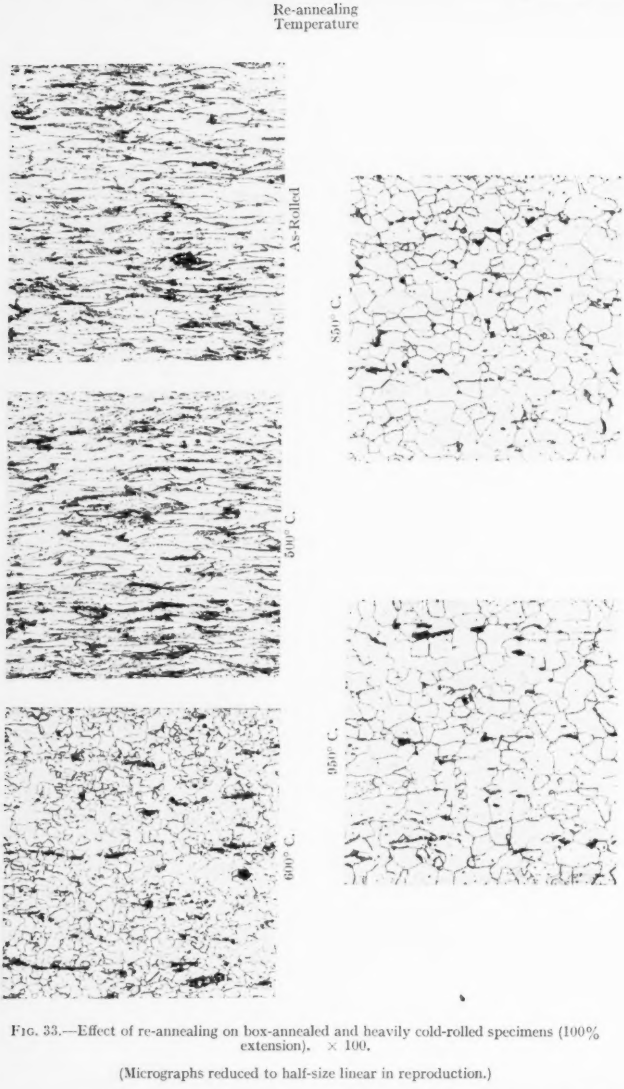


FIG. 33.—Effect of re-annealing on box-annealed and heavily cold-rolled specimens (100% extension). × 100.

(Micrographs reduced to half-size linear in reproduction.)

[*Edwards and others.*

[*To face p.* 129 P.

It should be mentioned that, in the case of pot-annealing, no attempt was made to reach a temperature of above 900° C.; indeed, this was intentionally avoided, the object being to obtain much larger crystals than in the normalised specimen. It must be remembered, however, that this involves the production of ferrite crystals which are elongated in the direction of rolling.

Another point which it is desirable to emphasise is that, under the conditions which prevail inside an annealing pot, coupled with the prolonged time during which the contents are at a temperature above a red heat, there is a tendency for decarburisation to occur. With normalising, on the other hand, whilst some scaling or surface oxidation of the metal takes place, there is practically no removal of carbon from the steel itself.

In considering the results obtained from steel sheets, such as have been used in the present investigation, and, indeed, from all ordinary commercial sheets, it is necessary to bear in mind that there are certain irregularities in the chemical composition of different parts of the same sheet. In some respects this is more marked in the case of sheets made from rimming steel than in that of rising steel, or than would be the case in dead-melted steel. The reason for this is that, during the solidification of rimming steel, a solid shell or rim is formed which may be about 2 in. thick in an ingot which is 12 in. square in cross-sectional area. This rimmed portion of the steel is not only free from blow-holes, but is very much purer than the average composition of the ingot. That is to say, it contains substantially less carbon, phosphorus and sulphur, as well as oxygen, than the inner zones of the ingot. This relatively pure solid rim is maintained in the steel bar from which the sheets are rolled. A sulphur print of a cross-section of the steel bar used in the present experiments is shown in Fig. 26 (Plate VI.), which illustrates the variation in sulphur content; a similar degree of segregation applies to carbon and phosphorus.

As in the sheet-rolling mills, the rolling is carried on at right angles to the direction of bar rolling. It naturally follows that the effect is to produce a relatively large area of sheet in which the percentages of carbon, phosphorus, and sulphur are very low. These differences alone will give rise to variations in the properties of the finished sheet, according to the positions from which the test-pieces are taken. With the object of minimising the errors which might arise from these irregularities of composition, and to bring out as prominently as possible the effects of the cold-rolling and subsequent annealing temperature, the following plan was adopted.

Selection of Test-Pieces.—As previously mentioned, one sheet from each double was box-annealed, and the other normalised, prior to cold-rolling. The diagram in Fig. 9 indicates the system adopted for the selection of the test-pieces for the tensile and Erichsen tests.

Each sheet, 72 in. long by 27 in. wide, was cut into two for convenience of handling in the blanking press, the relative positions

of the two halves being carefully noted by stamping identification marks on each portion. As shown in the diagram, a strip for Erichsen testing 27 in. long by 3 in. wide was cut from the top or "curl" end of the sheet, a second strip being cut from the middle of the top half sheet, and further strips from the side and tail or "scrap" end of the lower half sheet. The tensile test-pieces, blanked out as shown in the figure, were carefully numbered in

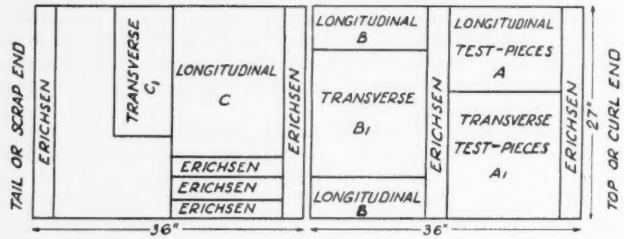


FIG. 9.

such a way that subsequent selection for treatment at each annealing temperature would include samples from the top or "curl" end, middle and "scrap" end of the sheet. Thus, for each annealing temperature, longitudinal test-pieces would be taken from A, B, and C. Similarly, transverse test-pieces would be taken from A_1, B_1 and C_1 for each annealing temperature. In just the same manner, the Erichsen pieces were taken so as to be representative of the whole area of the sheet.

Consideration of Results.

As a preliminary step in the direction of an examination and discussion of the results obtained, a brief reference to the effects of cold-rolling itself will not be out of place.

It is true that neither the manufacturers nor the users of large steel sheets have any obvious reasons for being interested in the properties of cold-rolled sheets before they are annealed. But, as previously suggested, in so far as the inner crystalline character of the material, prior to cold-rolling, may have an effect on the properties after annealing, it is desirable to emphasise any facts which will tend to reveal this in a tangible form.

For the purpose the authors have in mind at the moment, it is unnecessary to refer to all the tensile properties. The object will be served by considering the ultimate breaking stresses of specimens which had been normalised on the one hand, and pot-annealed on the other, and then cold-rolled to varying degrees. These data have been plotted in Fig. 10 for each condition of heat treatment, both for the longitudinal and transverse directions of rolling.

With the exception of the 5% and 10% extensions, it will be

seen that the results lie on relatively smooth curves. There is, however, a distinct tendency for the results corresponding with the 5% extension to be rather on the high side. It is thought that this tendency is definitely due to the surface irregularities of the sheet before cold-rolling being flattened out and causing a greater degree of work-hardening than would normally be anticipated from a perfectly smooth sheet subjected to the same degree of extension.

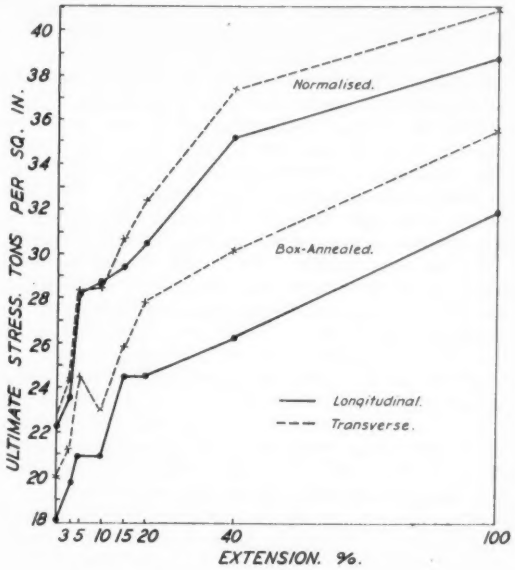


FIG. 10.

In the case of the pot-annealed specimens with 10% cold-rolling extensions, the results are distinctly on the low side, both when tested in the direction of, and at right angles to, the direction of rolling. There can be no doubt that this anomaly has been caused by the ferrite crystals after annealing being much larger in this instance than was the case for the other specimens of the series. This difference of crystal size is to be explained on the basis that the finishing temperature during hot-rolling was such as to render the material sensitive to crystal growth after annealing below 900° C.

From these curves, it is evident that, after submitting the pot-annealed specimens to 100% extensions by cold-rolling, the mean ultimate stress in the two directions of rolling is only about equal to the corresponding value produced by approximately 25% exten-

sion of the normalised material. This clearly illustrates the greater hardening effects of a given amount of cold-work with diminishing crystal size. Hence, whatever beneficial objects are aimed at by cold-rolling and low-temperature annealing can be achieved by a smaller degree of cold-rolling as the initial crystal size decreases.

It will have been gathered, from the description of the manner in which each experimental sheet was cut up for testing, that three tensile test-pieces in each direction were used for each annealing temperature. In the case of the elastic limit, or limit of proportionality, only two determinations were made, and it is the mean of these two results which is given in the Tables.

After detaching the extensometer, the yield point was observed by the usual method of noting the drop of the beam. It was found, however, that the values obtained in this way were consistently lower by about 1 to 1½ tons per sq. in., than was obtained when making the yield point determination with the third specimen, to which the extensometer had not been attached. This discrepancy was obtained, although the rate of loading was the same in each case; and, in consequence, it was rather difficult to decide what to do with the different results. But, after careful consideration, it was thought better to ignore the results of the yield points that were obtained in those cases where the limit of proportionality had been previously determined. Therefore, the yield point figures given in the Tables represent one determination only.

With regard to the ultimate breaking loads and elongations, three tests were made in each instance. To avoid the unnecessary reproduction of a multiplicity of figures, however, the averages of these values have been computed, and it is these averages which are given in Tables VIII. to XIV., and XV. to XXI. for the normalised and pot-annealed specimens respectively.

Considering the nature of the work in general, particularly as regards the possible difference in carbon content in the various parts of a given sheet, the variations in the values obtained from each set of three samples were remarkably small. To illustrate the extent of this, three sets of results are given in Table XXII., which may be regarded as representing the upper limits of the variations obtained.

It will thus be seen that the data, as a whole, can be accepted as giving a reliable indication of the effects of varying degrees of cold-rolling and annealing.

Erichsen Tests.—In spite of what has already been said concerning the limitations of this test as a means of ascertaining the drawability of steel sheets, in the absence of any definitely recognised method of estimating this property, it was felt that this test should be made for purposes of comparison with the tensile properties of the material when in a corresponding condition. Accordingly, four such tests have been made for each annealing temperature, and the averages of these are given in Tables VIII. to XIV., and XV. to XXI. for the normalised and box-annealed specimens, respectively.

TABLE VIII.—*Material Normalised before Cold-Rolling; 0% Extension.*

Annealing Temperature. ° C.	Direction.*	Ultimate Stress. Tons per sq. in.	Yield Point. Tons per sq. in.		Elastic Limit. Tons per sq. in.	Elongation. %		Erichsen Value.	Rockwell Value.	Brinell Value.
			(1).†	(2).‡		On 8 in.	On 2 in.			
As-rolled	L.	22·3	14·0	13·9	13·0	26·4	35·2	10·53	41·2	96·8
	T.	22·7	14·5	15·2	13·0	24·2	35·0	...	...	...
500	L.	...	...	...	...	...	...	10·63	37·1	88·5
550	L.	...	...	...	...	...	...	10·88	37·2	91·9
600	L.	...	...	...	...	...	...	10·73	35·6	87·8
650	L.	...	...	...	...	...	...	10·51	35·8	88·7
700	L.	...	...	...	...	...	...	11·10	36·0	89·5
750	L.	...	...	...	...	...	...	10·54	34·8	83·1
800	L.	...	...	...	...	...	...	10·28	37·7	85·5
850	L.	...	...	...	...	...	...	10·23	37·5	85·3
900	L.	20·3	12·0	11·7	10·7	26·9	36·1	10·41	36·9	86·9
	T.	20·5	12·6	13·0	10·6	28·0	39·3	...	...	...
950	L.	20·0	10·8	12·2	10·1	29·4	40·2	10·32	35·9	89·2
	T.	20·0	11·2	11·9	10·3	29·9	41·6	...	...	...

TABLE IX.—*Material Normalised before Cold-Rolling; 5% Extension.*

Annealing Temperature. ° C.	Direction.*	Ultimate Stress. Tons per sq. in.	Yield Point. Tons per sq. in.		Elastic Limit. Tons per sq. in.	Elongation. %		Erichsen Value.	Rockwell Value.	Brinell Value.
			(1).†	(2).‡		On 8 in.	On 2 in.			
As-rolled	L.	28·2	22·8	24·0	20·2	9·4	17·2	8·98	70·5	141·8
	T.	28·3	23·0	23·0	19·5	9·7	16·0	...	...	...
500	L.	22·5	16·6	18·5	15·8	20·5	31·1	9·87	61·3	112
	T.	22·4	18·6	19·1	16·1	21·3	32·3	...	...	...
550	L.	22·5	16·7	16·7	16·0	21·6	32·2	9·99	59·1	108
	T.	22·1	17·5	16·9	16·8	22·9	33·1	...	...	...
600	L.	22·7	15·7	16·4	14·8	21·2	33·1	10·27	57·7	105
	T.	23·1	16·6	17·1	15·9	22·3	33·8	...	...	...
650	L.	21·8	14·4	15·1	13·9	25·0	34·5	10·08	57·7	104
	T.	21·9	15·3	16·3	14·3	24·7	35·1	...	...	...
700	L.	18·7	11·4	8·1	8·0	15·5	23·3	10·02	37·5	85·4
	T.	19·6	11·6	10·0	10·0	21·3	28·6	...	...	...
750	L.	17·6	5·2	5·7	4·1	26·1	32·7	10·03	37·5	88·2
	T.	18·0	4·6	6·0	3·1	24·8	31·0	...	...	...
800	L.	18·1	6·8	6·9	4·9	22·0	28·0	10·06	42·5	90·3
	T.	18·3	5·3	5·1	3·5	25·8	34·4	...	...	...
850	L.	18·5	10·8	6·6	7·2	22·9	28·7	10·46	43·0	91·2
	T.	19·3	7·6	10·0	6·8	22·6	29·6	...	...	...
900	L.	20·1	9·4	10·7	9·0	28·3	38·7	10·20	42·1	90·7
	T.	20·0	10·0	10·9	9·1	28·2	39·3	...	...	...
950	L.	20·3	9·7	12·1	8·6	28·2	39·3	10·71	41·5	87·9
	T.	20·3	10·2	13·6	9·2	27·9	40·0	...	...	...

* L. = Longitudinal; T. = Transverse. † Mean of two values with extensometer.
‡ One value without extensometer.

TABLE X.—*Material Normalised before Cold-Rolling; 10% Extension.*

Annealing Temperature. ° C.	Direction.*	Ultimate Stress. Tons per sq. in.	Yield Point. Tons per sq. in.		Elastic Limit. Tons per sq. in.	Elongation. %		Erichsen Value.	Rockwell Value.	Brinell Value.
			(1).†	(2).‡		On 8 in.	On 2 in.			
As-rolled	L.	28·7	22·6	22·4	21·0	7·9	14·3	8·14	70·0	144
	T.	28·5	22·1	22·2	20·1	7·6	14·2	...	...	...
500	L.	23·9	19·5	18·3	19·0	16·1	26·7	9·53	61·5	107
	T.	23·5	19·5	18·3	19·1	17·7	28·9	...	...	...
550	L.	23·5	18·1	18·1	17·5	15·9	26·2	9·73	61·7	108
	T.	23·2	18·8	19·1	18·4	16·3	27·4	...	...	...
600	L.	23·0	16·8	16·6	16·4	20·6	31·2	9·79	60·9	109
	T.	22·6	16·7	18·0	16·1	20·2	29·2	...	...	...
650	L.	22·5	15·0	16·3	14·3	21·7	29·6	10·08	54·4	100
	T.	22·5	15·8	17·1	15·4	20·9	34·2	...	...	...
700	L.	18·5	5·6	5·4	3·8	20·5	31·5	9·96	37·2	87·3
	T.	19·4	5·1	5·9	3·5	21·6	32·5	...	...	...
750	L.	17·9	4·2	3·9	3·4	25·4	30·8	10·35	36·8	85·1
	T.	18·7	4·7	4·4	3·7	24·2	29·5	...	...	...
800	L.	18·1	4·1	5·4	2·7	24·1	29·8	10·27	37·5	88·0
	T.	18·9	4·9	5·7	3·4	24·5	32·8	...	...	...
850	L.	18·3	4·7	5·4	3·5	26·9	34·1	10·52	43·1	92·3
	T.	19·2	4·9	5·0	3·6	25·2	33·5	...	...	...
900	L.	18·7	5·2	5·2	3·8	26·1	34·8	11·38	43·1	92·6
	T.	19·5	5·3	6·6	4·6	26·5	36·0	...	...	...
950	L.	20·6	9·7	10·9	9·4	29·4	42·2	11·46	43·6	90·3
	T.	20·1	9·9	11·5	9·7	29·5	42·6	...	...	...

TABLE XI.—*Material Normalised before Cold-Rolling; 15% Extension.*

Annealing Temperature. ° C.	Direction.*	Ultimate Stress. Tons per sq. in.	Yield Point. Tons per sq. in.		Elastic Limit. Tons per sq. in.	Elongation. %		Erichsen Value.	Rockwell Value.	Brinell Value.
			(1).†	(2).‡		On 8 in.	On 2 in.			
As-rolled	L.	29·4	25·4	23·9	23·8	4·9	10·5	8·48	74·6	139
	T.	30·6	23·7	23·7	22·2	4·7	9·1	...	...	...
500	L.	...	...	...	...	...	...	9·25	67·5	116
550	L.	...	...	...	...	...	...	9·24	66·9	115
600	L.	...	...	...	...	...	...	9·59	61·9	109
650	L.	...	...	...	...	...	...	11·17	42·0	84·8
700	L.	19·1	7·2	7·6	6·6	27·2	36·2	11·30	41·0	81·5
	T.	19·7	7·7	9·0	6·5	27·8	40·0	...	...	...
750	L.	18·8	6·5	5·6	6·0	26·6	35·7	11·25	39·8	81·5
	T.	19·2	7·6	7·8	6·8	26·2	38·4	...	...	...
800	L.	18·8	7·3	7·8	6·3	27·9	38·5	11·51	39·8	81·3
	T.	19·3	7·8	8·3	6·9	28·1	39·9	...	...	...
850	L.	18·8	7·2	8·1	6·4	26·8	36·7	11·54	39·5	83·0
	T.	19·4	8·3	9·1	7·1	26·6	37·4	...	...	...
900	L.	...	...	...	...	...	...	11·40	42·5	84·2
950	L.	...	...	...	...	...	...	11·26	42·6	87·7

* L. = Longitudinal; T. = Transverse. † Mean of two values with extensometer.
‡ One value without extensometer.

TABLE XII.—*Material Normalised before Cold-Rolling; 20% Extension.*

Annealing Temperature. ° C.	Direction.*	Ultimate Stress. Tons per sq. in.	Yield Point. Tons per sq. in. (1).†	Yield Point. Tons per sq. in. (2).‡	Elastic Limit. Tons per sq. in.	Elongation. %. On 8 in.	Elongation. %. On 2 in.	Erichsen Value.	Rockwell Value.	Brinell Value.
As-rolled	L.	30·5	27·6	27·6	24·7	3·8	7·2	8·45	78·9	154
	T.	32·4	27·6	28·0	24·3	2·4	6·2	...	...	...
500	L.	25·4	22·0	21·9	21·1	11·6	20·7	9·09	70·4	134
	T.	26·6	22·4	23·4	21·6	10·9	19·4	...	...	...
550	L.	24·3	20·7	20·0	20·1	14·0	23·1	9·42	65·8	116
	T.	25·4	21·3	21·9	20·7	11·1	20·1	...	...	...
600	L.	21·1	12·1	11·9	11·6	14·3	28·3	9·66	63·2	111
	T.	22·0	13·4	12·5	12·9	14·3	23·0	...	...	...
650	L.	19·6	8·3	8·9	7·5	29·5	40·4	11·38	41·4	86·7
	T.	20·3	8·8	9·9	8·4	29·1	41·5	...	...	...
700	L.	19·2	8·1	10·0	7·5	31·2	42·7	11·41	39·2	86·7
	T.	20·7	8·8	9·3	7·7	30·2	42·7	...	...	...
750	L.	18·8	7·8	10·0	7·0	31·4	43·5	11·42	38·5	82·8
	T.	19·5	8·5	10·7	7·8	27·7	40·5	...	...	...
800	L.	19·3	8·2	8·8	7·0	29·3	41·8	11·12	40·6	81·8
	T.	19·9	8·9	10·9	8·1	26·8	39·2	...	...	...
850	L.	19·2	8·6	9·4	8·2	30·4	41·1	10·96	39·5	80·7
	T.	19·9	9·0	10·0	8·2	27·6	41·3	...	...	...
900	L.	19·6	8·9	10·6	7·2	28·7	41·2	11·59	39·7	85·8
	T.	20·3	9·1	11·9	8·5	27·3	40·0	...	...	...
950	L.	19·9	9·5	10·2	9·3	30·5	41·6	11·23	42·0	82·2
	T.	20·4	9·5	12·1	9·2	28·5	40·4	...	...	...

TABLE XIII.—*Material Normalised before Cold-Rolling; 40% Extension.*

Annealing Temperature. ° C.	Direction.*	Ultimate Stress. Tons per sq. in.	Yield Point. Tons per sq. in. (1).†	Yield Point. Tons per sq. in. (2).‡	Elastic Limit. Tons per sq. in.	Elongation. %. On 8 in.	Elongation. %. On 2 in.	Erichsen Value.	Rockwell Value.	Brinell Value.
As-rolled	L.	35·2	33·9	33·3	31·4	2·5	5·8	7·45	83·5	164
	T.	37·4	33·5	34·4	31·0	2·2	4·9	...	...	...
500	L.	28·3	24·1	25·9	23·3	10·1	16·3	8·24	77·3	135
	T.	29·5	26·1	24·4	25·5	7·9	13·7	...	...	...
550	L.	24·8	19·4	19·8	19·3	10·9	22·0	10·08	55·9	104
	T.	25·7	22·3	20·0	21·4	8·7	15·0	...	...	...
600	L.	20·5	10·2	11·4	9·4	29·5	42·5	10·62	49·4	97·5
	T.	20·3	10·1	13·1	9·4	30·8	41·6	...	...	...
650	L.	20·2	10·2	12·1	10·2	29·1	42·4	11·05	44·7	91·1
	T.	20·3	10·1	13·9	10·1	30·1	42·2	...	...	...
700	L.	19·8	10·4	10·6	10·4	29·5	43·4	11·05	43·9	90·7
	T.	20·2	10·3	10·9	10·0	28·5	42·2	...	...	...
750	L.	19·6	10·1	11·9	9·7	28·5	41·6	11·19	42·2	88·9
	T.	20·2	10·3	9·4	10·0	27·7	41·9	...	...	...
800	L.	19·7	9·5	10·9	9·0	27·0	40·0	11·16	43·3	88·6
	T.	20·0	9·5	10·1	9·8	29·1	42·0	...	...	...
850	L.	20·2	10·8	12·6	10·1	29·6	42·3	11·08	42·9	90·2
	T.	20·4	10·7	11·1	9·8	28·1	40·4	...	...	...
900	L.	19·9	9·8	9·7	9·3	26·5	37·7	11·23	42·3	88·8
	T.	19·9	10·0	10·3	9·5	27·3	40·2	...	...	...
950	L.	20·0	9·1	10·7	9·0	26·4	40·2	11·45	42·5	90·3
	T.	19·7	9·7	9·3	8·8	27·1	40·2	...	...	...

* L. = Longitudinal; T. = Transverse. † Mean of two values with extensometer.
‡ One value without extensometer.

TABLE XIV.—*Material Normalised before Cold-Rolling; 100% Extension.*

Annealing Temperature. ° C.	Direction.*	Ultimate Stress. Tons per sq. in.	Yield Point. Tons per sq. in.		Elastic Limit. Tons per sq. in.	Elongation. %		Erichsen Value.	Rockwell Value.	Brinell Value.
			(1).†	(2).‡		On 8 in.	On 2 in.			
As-rolled	L.	38·6	...	...	...	1·1	3·5	6·17	87·8	188
	T.	40·9	...	...	...	1·1	2·9	...	...	...
500	L.	32·6	29·8	30·0	29·4	8·2	13·7	7·04	82·3	161
	T.	33·7	31·0	32·3	30·3	7·0	12·5	...	...	...
550	L.	26·7	23·0	22·1	22·6	8·8	15·0	7·51	80·9	156
	T.	28·1	24·7	24·3	24·5	8·0	17·0	...	...	...
600	L.	21·1	12·9	10·8	12·2	33·6	46·1	11·22	53·2	98
	T.	21·5	13·1	14·6	12·5	30·0	44·7	...	...	...
650	L.	20·9	12·9	14·4	12·5	32·5	45·4	11·06	53·3	94·4
	T.	21·1	13·1	14·6	13·0	32·8	46·2	...	...	...
700	L.	20·2	11·1	14·5	10·7	31·5	45·2	10·95	47·1	90·5
	T.	20·8	12·1	14·8	12·0	31·7	44·9	...	...	...
750	L.	20·3	11·0	10·8	10·7	31·2	45·5	11·02	44·2	92·8
	T.	20·5	11·5	13·8	11·2	32·2	45·5	...	...	...
800	L.	20·4	11·5	12·6	11·1	31·0	43·0	10·97	44·5	91·8
	T.	20·5	12·1	14·6	11·5	30·0	43·6	...	...	...
850	L.	20·2	11·3	13·8	11·0	31·4	46·1	11·20	44·2	90·3
	T.	20·4	11·5	10·9	11·1	30·5	41·8	...	...	...
900	L.	19·7	10·3	12·6	10·0	31·7	44·2	11·08	43·8	90·6
	T.	20·5	11·3	12·2	11·0	29·8	43·4	...	...	...
950	L.	20·4	10·5	12·0	9·9	29·3	41·9	11·13	43·6	90·3
	T.	20·6	10·4	13·6	10·0	29·1	40·1	...	...	...

TABLE XV.—*Material Box-Annealed before Cold-Rolling; 0% Extension.*

Annealing Temperature. ° C.	Direction.*	Ultimate Stress. Tons per sq. in.	Yield Point. Tons per sq. in.		Elastic Limit. Tons per sq. in.	Elongation. %		Erichsen Value.	Rockwell Value.	Brinell Value.
			(1).†	(2).‡		On 8 in.	On 2 in.			
As-rolled	L.	18·1	8·6	8·5	7·0	30·3	38·6	10·70	28·6	89·6
	T.	20·0	9·5	9·1	8·4	26·5	36·3	...	...	...
500	L.	...	...	...	...	...	...	10·30	30·4	88·7
550	L.	...	...	...	...	...	...	10·37	28·8	83·6
600	L.	...	...	...	...	...	...	10·67	28·8	83·9
650	L.	...	...	...	...	...	...	10·35	29·5	83·9
700	L.	...	...	...	...	...	...	11·14	27·1	82·2
750	L.	...	...	...	...	...	...	10·75	27·3	81·0
800	L.	...	...	...	...	...	...	10·24	26·5	78·9
850	L.	...	...	...	...	...	...	10·18	29·9	82·4
900	L.	17·7	9·3	9·9	7·8	28·7	37·3	10·08	29·5	83·6
	T.	20·0	10·4	10·9	9·1	24·6	33·1	...	...	...
950	L.	19·3	10·3	11·4	9·3	29·4	37·0	10·26	34·4	82·4
	T.	19·7	10·2	11·8	9·6	28·8	40·1	...	...	...

* L. = Longitudinal; T. = Transverse. † Mean of two values with extensometer.
‡ One value without extensometer.

TABLE XVI.—*Material Box-Annealed before Cold-Rolling; 5% Extension.*

Annealing Temperature. ° C.	Direction.*	Ultimate Stress. Tons per sq. in.	Yield Point. Tons per sq. in.		Elastic Limit. Tons per sq. in.	Elongation. %		Erichsen Value.	Rockwell Value.	Brinell Value.
			(1).†	(2).‡		On 8 in.	On 2 in.			
As-rolled	L.	20·9	17·8	19·1	15·3	9·0	16·2	8·49	55	116
	T.	24·5	20·2	21·2	16·4	9·3	14·3	...	...	...
500	L.	18·6	12·0	12·5	11·0	21·5	30·1	9·43	52·8	105
	T.	21·2	14·1	13·8	13·0	19·7	26·8	...	...	...
550	L.	17·9	10·0	11·9	10·0	23·9	32·3	9·82	49·3	97·2
	T.	20·9	13·2	12·9	12·0	23·4	32·4	...	...	...
600	L.	18·0	10·7	11·2	9·6	26·0	36·8	9·43	47	97·0
	T.	20·0	12·3	12·4	11·8	25·2	35·1	...	...	...
650	L.	18·2	10·5	11·5	9·5	27·9	35·9	9·62	45·3	98·4
	T.	20·0	12·1	12·3	11·7	25·5	33·6	...	...	...
700	L.	18·1	10·0	11·3	9·4	25·9	33·4	9·89	40·5	87·7
	T.	20·4	12·5	12·5	10·4	25·6	33·8	...	...	...
750	L.	17·5	9·1	10·3	8·1	26·2	35·1	10·06	38·3	88·4
	T.	19·4	9·0	9·9	8·4	24·5	33·3	...	...	...
800	L.	17·6	9·0	8·7	8·4	25·1	29·7	9·91	37·3	88·7
	T.	19·0	7·3	8·1	6·0	20·4	24·2	...	...	...
850	L.	17·5	9·5	9·1	8·4	28·0	37·1	10·34	34·3	87·7
	T.	19·9	10·2	11·2	9·4	22·2	29·1	...	...	...
900	L.	18·5	8·0	9·4	7·6	28·1	37·7	10·44	36·4	92·0
	T.	19·9	8·9	10·5	8·0	28·0	38·7	...	...	...
950	L.	19·8	9·9	10·9	8·5	29·4	39·5	11·30	38·5	85·1
	T.	19·9	9·4	9·3	8·8	28·4	40·5	...	...	...

TABLE XVII.—*Material Box-Annealed before Cold-Rolling; 10% Extension.*

Annealing Temperature. ° C.	Direction.*	Ultimate Stress. Tons per sq. in.	Yield Point. Tons per sq. in.		Elastic Limit. Tons per sq. in.	Elongation. %		Erichsen Value.	Rockwell Value.	Brinell Value.
			(1).†	(2).‡		On 8 in.	On 2 in.			
As-rolled	L.	20·9	16·2	16·6	15·1	7·0	10·2	7·06	59·4	115
	T.	23·0	17·0	17·3	15·9	4·4	8·5	...	...	...
500	L.	18·9	12·1	12·8	11·1	16·1	21·7	8·69	54·7	104
	T.	20·2	13·2	12·4	12·0	10·7	16·7	...	...	...
550	L.	18·7	11·7	12·0	10·4	17·3	23·5	8·78	52·2	104
	T.	20·2	11·1	14·3	10·5	13·7	18·2	...	...	...
600	L.	18·2	9·9	11·0	9·3	18·8	24·4	8·85	48·7	103
	T.	19·9	10·9	14·0	8·9	16·3	21·8	...	...	...
650	L.	18·0	10·0	9·7	9·0	19·3	27·2	9·18	45·7	98·8
	T.	19·6	9·8	13·0	8·5	17·5	23·1	...	...	...
700	L.	17·3	8·5	9·2	6·9	20·5	26·1	9·55	39·9	95·8
	T.	19·3	9·9	9·0	9·4	17·1	23·0	...	...	...
750	L.	17·1	6·5	6·2	5·0	20·4	25·8	9·59	37·9	93·7
	T.	18·6	4·6	5·6	3·7	19·7	26·4	...	...	...
800	L.	17·1	6·8	6·9	5·1	20·0	28·5	9·39	39·7	93·9
	T.	18·5	6·2	6·9	4·8	20·3	27·3	...	...	...
850	L.	17·2	6·2	5·8	4·3	20·8	27·8	10·15	35·8	93·7
	T.	18·7	7·0	6·8	5·3	18·1	23·7	...	...	...
900	L.	17·2	6·8	6·8	6·2	19·8	25·2	11·19	38·5	92·0
	T.	18·7	6·7	7·3	5·9	21·5	22·3	...	...	...
950	L.	19·6	8·2	7·7	7·4	25·5	37·9	11·61	40·3	91·6
	T.	19·9	8·6	8·6	8·6	30·7	40·8	...	...	...

* L. = Longitudinal; T. = Transverse. † Mean of two values with extensometer.
‡ One value without extensometer.

TABLE XVIII.—*Material Box-Annealed before Cold-Rolling; 15% Extension.*

Annealing Temperature. ° C.	Direction.*	Ultimate Stress. Tons per sq. in.	Yield Point. Tons per sq. in. (1).†	Yield Point. Tons per sq. in. (2).‡	Elastic Limit. Tons per sq. in.	Elongation. %. On 8 in.	Elongation. %. On 2 in.	Erichsen Value.	Rockwell Value.	Brinell Value.
As-rolled	L.	24·5	21·7	21·7	20·7	4·8	9·8	7·74	63·8	122
	T.	25·8	21·0	22·0	20·1	3·9	8·9	...	...	...
500	L.	...	...	...	...	...	...	8·38	60·2	106
550	L.	...	...	...	...	...	...	8·58	60·6	108
600	L.	...	...	...	...	...	...	8·90	56·5	103
650	L.	...	...	...	...	...	...	10·14	43·7	87·7
700	L.	18·9	7·9	7·5	7·4	24·2	33·8	11·15	39·0	86·7
	T.	19·5	6·7	8·1	6·0	25·6	36·5	...	...	...
750	L.	19·0	7·2	8·0	6·3	27·4	37·2	10·99	38·3	88·4
	T.	19·5	7·6	8·1	6·6	29·0	39·7	...	...	...
800	L.	19·1	7·8	8·5	6·9	25·8	33·6	11·01	38·7	85·1
	T.	19·4	7·6	7·7	7·2	26·7	37·5	...	...	...
850	L.	19·0	7·2	8·1	6·6	28·4	38·9	11·07	38·1	86·1
	T.	19·2	7·8	7·5	7·2	25·9	37·8	...	...	...
900	L.	...	...	...	...	...	...	11·61	38·5	84·8
950	L.	...	...	...	...	...	...	11·75	40·0	84·8

TABLE XIX.—*Material Box-Annealed before Cold-Rolling; 20% Extension.*

Annealing Temperature. ° C.	Direction.*	Ultimate Stress. Tons per sq. in.	Yield Point. Tons per sq. in. (1).†	Yield Point. Tons per sq. in. (2).‡	Elastic Limit. Tons per sq. in.	Elongation. %. On 8 in.	Elongation. %. On 2 in.	Erichsen Value.	Rockwell Value.	Brinell Value.
As-rolled	L.	24·5	22·2	22·9	20·5	3·7	9·4	7·78	68·8	128
	T.	27·9	24·2	26·5	22·4	2·2	4·9	...	...	...
500	L.	23·6	18·8	18·5	18·0	13·0	21·0	8·18	64·6	114
	T.	23·9	18·5	18·8	17·6	11·6	19·3	...	...	...
550	L.	22·7	18·0	16·8	17·1	15·5	22·1	8·71	61·6	107
	T.	22·9	17·5	17·5	16·8	13·5	21·8	...	...	...
600	L.	20·6	13·4	11·7	12·4	17·2	26·1	8·68	58·4	107
	T.	21·8	13·7	16·0	12·7	18·3	29·5	...	...	...
650	L.	18·9	7·6	8·5	7·0	24·8	33·4	10·70	41·6	89
	T.	19·6	7·7	7·9	6·9	26·1	35·2	...	...	...
700	L.	19·1	7·8	7·4	7·2	28·6	38·5	11·20	38·3	83·3
	T.	19·8	8·0	8·8	7·3	23·8	31·7	...	...	...
750	L.	18·8	7·4	7·7	6·5	27·2	36·4	10·98	38·9	82·4
	T.	19·8	8·3	9·2	7·2	25·8	35·0	...	...	...
800	L.	19·0	7·6	7·4	6·8	26·3	35·2	10·72	40·2	86·1
	T.	19·6	7·8	7·6	7·0	25·8	33·3	...	...	...
850	L.	18·8	7·4	8·6	6·7	25·7	35·2	10·69	38·7	84·6
	T.	19·4	7·7	7·4	6·6	25·8	33·0	...	...	...
900	L.	18·9	7·8	8·0	7·4	23·9	34·3	10·84	39·1	85·1
	T.	19·4	7·7	9·1	7·4	23·7	32·1	...	...	...
950	L.	19·4	8·5	9·4	7·9	26·3	36·2	11·19	40·7	82·4
	T.	19·5	8·9	9·2	8·1	29·1	37·7	...	...	...

* L. = Longitudinal; T. = Transverse. † Mean of two values with extensometer.
‡ One value without extensometer.

TABLE XX.—*Material Box-Annealed before Cold-Rolling; 40% Extension.*

Annealing Temperature. ° C.	Direction.*	Ultimate Stress. Tons per sq. in.	Yield Point. Tons per sq. in. (1).†	Yield Point. Tons per sq. in. (2).‡	Elastic Limit. Tons per sq. in.	Elongation. % On 8 in.	Elongation. % On 2 in.	Erichsen Value.	Rockwell Value.	Brinell Value.
As-rolled	L.	26·2	23·1	26·6	20·9	2·1	4·3	6·69	73·7	134
	T.	30·2	25·5	29·5	22·9	1·5	4·0	...	...	...
500	L.	23·1	17·1	20·2	15·7	10·6	16·4	7·27	69·9	129
	T.	26·0	19·2	20·0	18·6	7·4	12·3	...	...	...
550	L.	21·8	15·5	17·1	13·8	13·6	20·7	8·31	57·1	110
	T.	23·9	17·0	18·0	15·6	10·9	16·3	...	...	...
600	L.	19·2	11·0	11·6	10·3	23·7	33·2	8·63	56·0	106
	T.	21·1	12·4	11·6	11·5	18·1	30·0	...	...	...
650	L.	18·7	8·1	10·7	7·9	27·6	38·0	10·56	39·3	86·4
	T.	19·6	8·7	9·6	7·8	27·3	37·1	...	...	...
700	L.	17·7	7·1	7·1	6·3	27·0	38·0	10·55	39·9	86·7
	T.	19·4	8·0	6·8	7·3	25·7	36·1	...	...	...
750	L.	18·5	7·3	7·3	5·7	27·5	39·4	10·62	37·8	88·7
	T.	19·3	8·0	7·5	7·3	26·8	37·5	...	...	...
800	L.	18·8	7·8	9·2	7·2	27·9	39·8	10·87	36·2	88·5
	T.	19·9	9·1	8·5	8·5	27·7	38·3	...	...	...
850	L.	18·9	7·7	7·4	7·3	29·8	40·4	10·89	37·6	87·0
	T.	19·7	8·7	9·9	8·3	28·2	39·2	...	...	...
900	L.	19·6	8·8	7·8	8·0	26·6	38·8	11·09	41·5	89·6
	T.	19·7	8·1	7·8	7·7	25·5	37·8	...	...	...
950	L.	19·5	8·8	8·0	8·4	26·9	40·1	11·37	40·4	87·5
	T.	19·4	8·3	9·0	8·0	25·7	37·4	...	...	...

TABLE XXI.—*Material Box-Annealed before Cold-Rolling; 100% Extension.*

Annealing Temperature. ° C.	Direction.*	Ultimate Stress. Tons per sq. in.	Yield Point. Tons per sq. in. (1).†	Yield Point. Tons per sq. in. (2).‡	Elastic Limit. Tons per sq. in.	Elongation. % On 8 in.	Elongation. % On 2 in.	Erichsen Value.	Rockwell Value.	Brinell Value.
As-rolled	L.	31·8	...	...	...	1·2	3·6	6·01	79·3	152
	T.	35·4	...	...	...	1·1	2·5	...	...	...
500	L.	28·4	24·8	25·0	23·6	9·3	14·7	6·80	75·8	144
	T.	31·1	27·5	28·2	26·0	6·9	11·1	...	...	...
550	L.	25·4	21·5	21·6	20·9	11·4	19·7	6·94	74·5	141
	T.	27·9	24·0	24·4	23·5	9·1	15·1	...	...	...
600	L.	19·7	11·0	12·4	10·8	30·7	39·9	10·63	58·6	105
	T.	20·7	12·2	13·5	12·0	26·7	37·0	...	...	...
650	L.	19·5	11·0	12·9	10·6	31·2	41·3	11·08	44·0	89·0
	T.	19·6	11·3	13·9	11·1	30·4	42·7	...	...	...
700	L.	19·3	9·2	12·1	9·1	32·4	44·9	10·85	42·6	88·4
	T.	20·0	11·3	13·0	10·9	29·6	43·0	...	...	...
750	L.	18·9	9·3	10·7	9·0	31·0	43·8	10·76	41·1	85·8
	T.	19·8	10·2	10·0	9·5	30·5	42·6	...	...	...
800	L.	19·1	9·6	8·2	9·0	29·7	43·2	10·83	39·9	87·0
	T.	19·9	10·0	10·5	9·1	29·6	42·2	...	...	...
850	L.	19·2	9·5	12·2	9·1	29·0	42·5	11·06	40·9	87·0
	T.	19·7	9·9	11·7	9·6	27·1	40·8	...	...	...
900	L.	18·7	10·3	9·3	9·3	28·2	41·4	11·09	41·8	87·3
	T.	19·7	9·7	11·3	9·5	29·0	42·0	...	...	...
950	L.	19·8	9·4	11·7	8·5	30·4	41·5	11·31	41·7	85·5
	T.	19·9	9·2	10·7	8·5	29·6	42·9	...	...	...

* L. = Longitudinal; T. = Transverse. † Mean of two values with extensometer.
‡ One value without extensometer.

TABLE XXII.—*Variations in Physical Properties of Samples of Cold-Rolled Steel Sheet.*

Normalised and cold-rolled to 40% extension; annealed 1 hr. at 750° C. Longitudinal samples.

Test. (Longitudinal.)	Ultimate Stress. Tons per sq. in.	Yield Point. Tons per sq. in.	Elastic Limit. Tons per sq. in.	Elongation. %.
1	19·8	10·1	9·7	26·5
2	19·9	10·2	9·8	29·7
3	19·0	11·9	...	29·0

NOTE: The yield point recorded for test 3 refers to the test in which no extensometer was used.

Hardness.—Both Brinell and Rockwell hardnesses have been determined, and these are also recorded in the Tables already referred to. The diameter of the ball used for the Brinell determinations was 1 mm., and the load was 30 kg.; for the Rockwell hardness test a ball diameter of $\frac{1}{16}$ in. and a load of 100 kg. were employed.

Tensile Properties.—Perhaps the most convenient means of illustrating the effects of the treatments under review is to plot the various results for each degree of cold-rolling against the corresponding annealing temperatures. This has been done, and the diagrams are reproduced in Figs. 11, 12, 13, 15, 16, and 17, and Figs. 14, 18, 19, 20, 21, and 22, for those specimens which were respectively normalised and pot-annealed before being cold-rolled.

TABLE XXIII.—*Properties of Material not Subjected to Cold-Rolling.*

Specimen—	As-Normalised.						
	Ultimate Strength. Tons per sq. in.	Yield Point. Tons per sq. in.	Elastic Limit. Tons per sq. in.	Elongation on 8 in. %.	Erichsen Value.	Rockwell Hardness No.	Brinell Hardness No.
Parallel with direction of rolling .	22·3	14·0	13·0	26·4	10·53	41·2	96·8
At right angles to direction of rolling .	22·7	14·7	13·0	24·2	...	...	...
	Re-Annealed at 950° C.						
Parallel with direction of rolling .	20·0	10·8	10·1	29·4	10·32	33·9	89·2
At right angles to direction of rolling .	20·0	11·5	10·3	29·9	...	...	...

Before proceeding to describe the results obtained after cold-rolling and annealing, it will be useful to draw attention to the properties of the material which has not been cold-rolled. For this purpose, in Table XXIII. the figures relating to the completely hot-rolled sheets in the commercially normalised condition and after laboratory annealing at 950° C. are given.

The explanation of these differences in the properties will be found on examining the microstructures of the specimens after the two treatments. These are shown in Fig. 27, from which it will be seen that the normalised specimen has a much finer crystal structure, owing to the more rapid rate at which it was cooled.

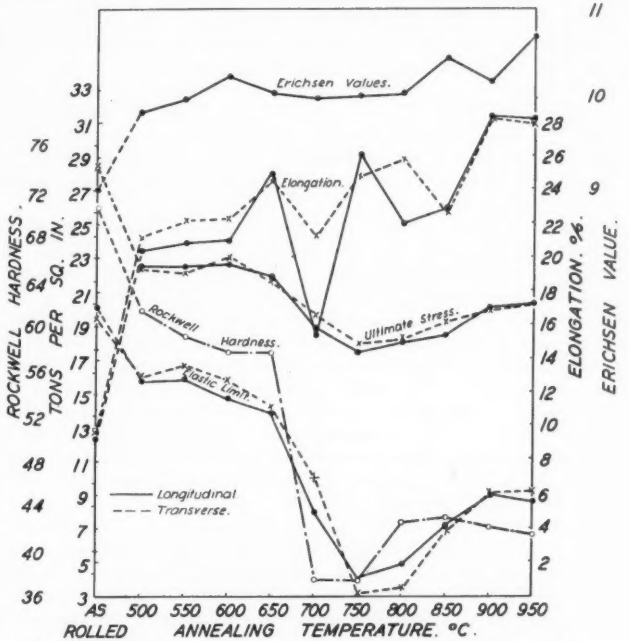


FIG. 11.—Sheets Normalised before Cold-Rolling; 5% extension.

Experiments on Normalised and Cold-Rolled Specimens.

Normalised Specimens Cold-Rolled to 5% Elongation.

The results for this set of experiments are plotted in Fig. 11, and a selected number of photomicrographs are shown in Fig. 28 (Plate VIII.). From the curves it will be seen that the lowest annealing temperature which was used throughout this investigation, namely,

500° C., produces an increase in the ductility of the material, which is represented by a decrease in the tensile strength of a little short of 6 tons per sq. in., and a corresponding change in the elastic limit of about 4 tons, whilst the elongation has increased by approximately 11% on 8 in., bringing the average of the two directions of testing up to nearly 21·0%. This tendency continues at a much slower rate as the annealing temperature is raised to 650° C. A much more marked change occurs at temperatures above 650° C., the elastic limits in particular falling to figures as low as 4·1 tons and 3·1 tons, respectively, on tests made parallel with and at right angles to the direction of rolling for an annealing temperature of 750° C. Over the same range of temperature the corresponding tensile strengths drop to 17·6 and 18·0 tons per sq. in. By further raising the temperature to 900° and 950° C., the elastic limit increases to, say, 9 tons, and the breaking stress to 20 tons.

With regard to the elongations over the range of temperature just referred to, these show no tendency to improve until 900° C. and 950° C. are reached, when the value of 28% is attained.

Microstructures.—The outstanding features of these curves will be readily understood after an examination of the microstructures which are shown in Fig. 28.

After annealing at 500° C., there was no indication of any structural change, and, in consequence, it must be assumed that the alterations in the tensile properties which occurred as a result of this treatment must be brought about as a consequence of the removal of the more intense stresses which are left in the material after rolling. The softening which took place, as a result of this partial removal of stresses, was not accompanied by recrystallisation or crystal growth. The range of temperature above 500° C., and up to 650° C., calls for no special comment because there was no abrupt change in the properties and no alteration in structure. At 650° C., however, there were definite indications of ferrite crystal growth, but this was irregular in character and became more and more pronounced as the annealing temperature was raised to 850° C. A reference to Fig. 28 will make this clear. This excessive crystal growth is the cause of the elastic limit and yield point values being so low. It will be noticed that there is an important decrease in the ultimate stress values resulting from the same cause, but the effect in this connection is not as marked as with the elastic limits and yield points.

As a matter of interest, it should be mentioned that the effects of these large crystals in producing such a marked lowering of the elastic limit, but only a small decrease in the corresponding ultimate breaking stress, is just what would be anticipated, so long as there is a moderate number of crystals in the section of the thickness of the sheet. In other words, the strain-hardening that occurs during the elongation of the specimen under these conditions of interference to slip at and near the crystal boundaries tends to raise the breaking

stress to something approximating to that of a more normal specimen, whereas the elastic limit is not affected in this way. The erratic values obtained for the elongations between 700° and 850° C. are certainly due to the presence of the large ferrite crystals.

Erichsen Tests.—For the purposes of comparison, these values have been plotted on the same diagram as the tensile results. It is rather remarkable to observe that over the whole range of anneal-

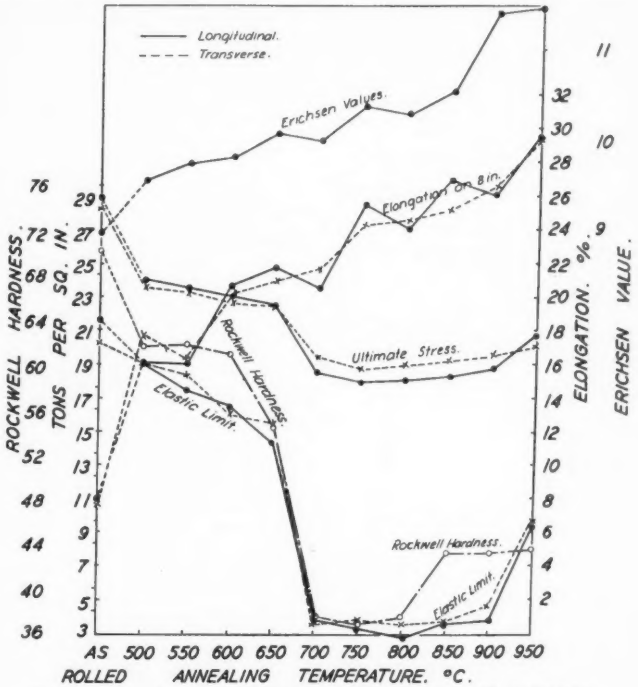


FIG. 12.—Sheets Normalised before Cold-Rolling; 10% extension.

ing temperatures, from 500° to 900° C., the Erichsen values are relatively very good, the figures being about 10·0 or a little over. In other words, this method of testing for the conditions prevailing in this series of experiments shows scarcely any discrimination between the specimens annealed at the various temperatures. This is an indication of the limitations of the Erichsen test, especially when it is remembered that the tensile properties of the various specimens are so widely different. The authors feel certain that

material possessing tensile properties such as are revealed in Fig. 11 for annealing temperatures up to 850° C., would fail if used in the production of a moderately difficult pressing under commercial conditions. For the low annealing temperatures, it would fail because of its high elastic limit and yield points, coupled with the low elongation; and for the higher ranges of annealing temperature on account of the differential plastic flow, resulting from the presence of such large crystals. In addition, the coarse grains resulting from material in this condition would give rise to roughening during pressing.

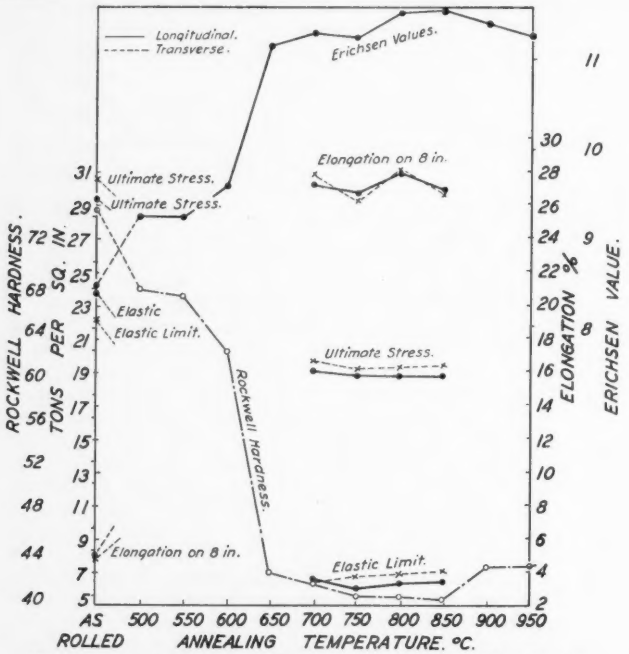


FIG. 13.—Sheets Normalised before Cold-Rolling; 15% extension.

Normalised Specimens Cold-Rolled to 10% *Elongation.*

The results for this series of experiments are illustrated in Fig. 12. It seems quite unnecessary to give a detailed description of these results, because the outstanding features are so very similar to those already discussed for the 5% cold-rolled specimens. In some respects the curves are, perhaps, a little more regular, and, in consequence of this, the salient points are somewhat more clearly

defined. What was said concerning the correlation of the microstructures and the properties, in connection with the 5% cold-rolled series, is equally applicable to those now submitted for consideration. In view of this, it was thought that it would be an undesirable duplication to reproduce any of the photomicrographs that were taken from this series.

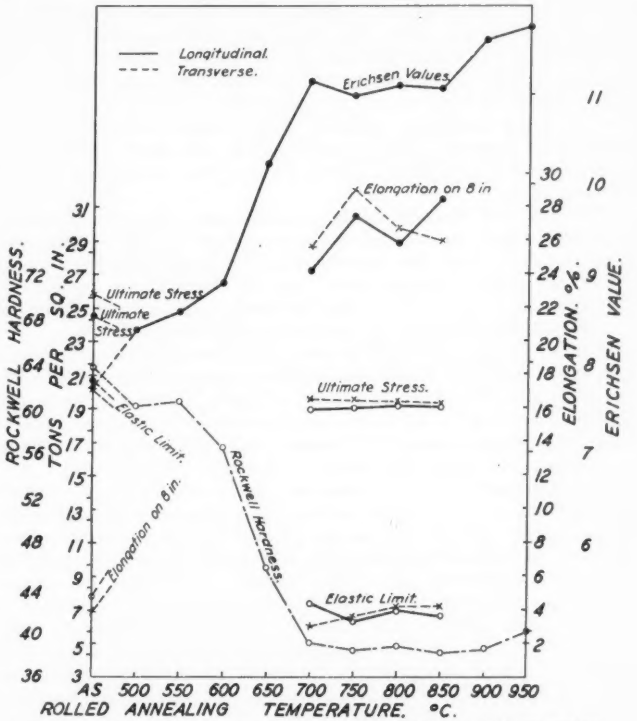


FIG. 14.—Sheets Box-Annealed before Cold-Rolling; 15% extension.

Normalised Specimens Cold-Rolled to 15% *Elongation.*

The preparation of, and the tests on the samples in this series were carried out after those for the higher degrees of cold-work. The results of the series cold-rolled to 20% extension having shown no evidence of coarse crystal growth, the series now under discussion was incorporated in order to determine, within narrower limits, the ranges of cold-rolling extensions which would give rise to coarse growth during subsequent annealing. For this purpose

it was considered unnecessary to carry out tensile tests on samples annealed over the temperature range 500–950° C., and thus only those annealed between 700° and 850° C. were examined. Erichsen and Rockwell tests, however, were carried out on specimens annealed over the whole range of temperature. The test results are depicted graphically in Fig. 13, and tabulated in Table XI.

Microstructures.—Quite briefly, it may be said that although some degree of crystal growth was observed in the microstructure, this was very much less than was the case for samples extended by 5 and 10%. The values for the elastic limit obtained in this series after annealing at temperatures between 700° and 850° C. are approximately 2 tons per sq. in. below those of the material in the fully annealed condition, whereas, in the series extended 10% and annealed at corresponding temperatures, the elastic limit values were approximately 6 tons below that of the material in its fully annealed state.

Erichsen and Rockwell Values.—Annealing at a temperature of 650° C. resulted in a marked improvement in these values over those obtained with the lower annealing temperatures, and with higher annealing temperatures, up to 900° C., a further but relatively small increase in the Erichsen value was observed, and a corresponding decrease in the Rockwell hardness figure.

Similar tests were made on material given an extension of 15% after box-annealing, the results of which are recorded in Table XVIII. and plotted in Fig. 14. The trend of these is very similar to those already described for the normalised material; in this case, however, the marked improvement in Erichsen and Rockwell values occurred at a somewhat higher temperature, namely, 700° C.

A consideration of the influence of the small degree of crystal growth which occurred on annealing these specimens at temperatures between 700° and 850° C. on the physical properties indicates that these would be quite suitable for a moderately difficult deep-drawing operation; however, the very marked roughening of the test-pieces observed during tensile testing suggests that pressings, say, for an outside panel in a motor-car body, manufactured from box-annealed sheets of similar quality to those used in this work, cold-rolled 15% and subsequently annealed at temperatures between 700° and 850° C., would be rejected because of the rough and unsightly appearance of the surface.

Normalised Specimens Cold-Rolled to 20% Elongation.

The curves for this series of experiments are shown in Fig. 15. From a glance at these it will be observed that they reveal some important differences, as compared with those previously referred to. First, they show a more or less steady improvement as the annealing temperature is raised up to about 600° C. This can be most conveniently described as resulting from the removal of cold-rolling stresses which is not accompanied by complete recrystallisa-

tion—such as occurs by annealing much more heavily cold-rolled material. At about 650° C., however, there is a sudden improvement in the ductility, which is more particularly evident in the marked increase in the figures for the elongation. The increase is due to the more complete and rapid removal of work-hardening as the amount of cold-work increases; this will become more obvious

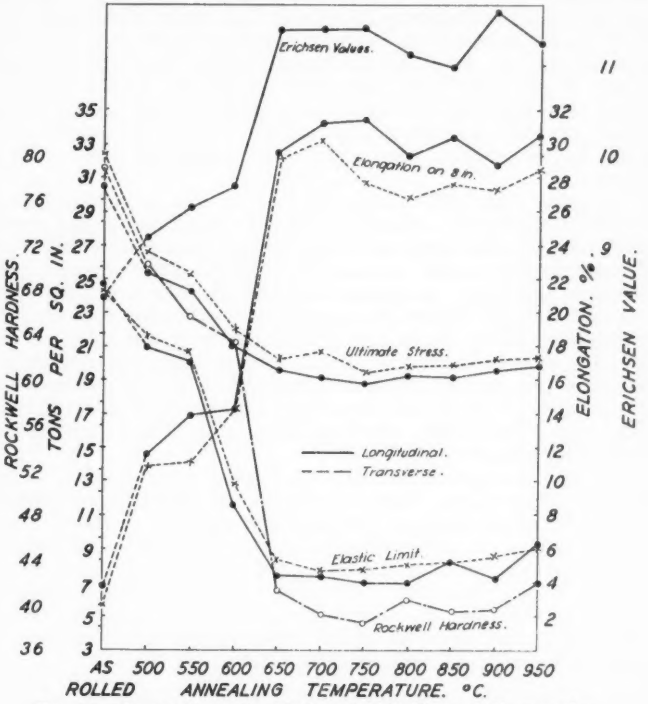


FIG. 15.—Sheets Normalised before Cold-Rolling; 20% extension.

after considering the specimens which have been submitted to still higher degrees of cold-rolling. For all annealing temperatures of 650–900° C., there is very little variation in the values for the elastic limits and yield points, and, if the average values of the longitudinal and transverse specimens are taken, it will be seen that the elastic limits are fairly constant, lying between 7·5 and 8·2 tons, whilst the corresponding average yield points are close to 8·6 tons. Both these values become a little higher after annealing at 950° C. Over the same range of annealing temperatures the figures for the ultimate

stress are also very steady, and the differences between the two directions of rolling are small.

With regard to the elongation, it is perhaps significant to note that, after annealing at 650° and 700° C., the two directions of rolling give closely concordant results; with higher annealing temperatures, however, the divergence becomes greater. In all probability this is due to the small crystals which exist after the low annealing temperature becoming somewhat larger when the temperature is raised; in this way the directional effects of rolling become greater. As will be seen on referring to the structures shown in Fig. 29 (Plate IX.), the only change which can be detected as a result of raising the annealing temperature above 650° C. is an increase in the size of the ferrite crystals. As this occurs, there is a small, but perceptible, tendency for the elongation to decrease in value.

Erichsen Test.—The results obtained by this method of testing are diagrammatically reproduced on the same chart as the tensile properties. In this instance, however, they more clearly reflect the changes in the tensile properties of the steel arising from the different annealing temperatures. Indeed, when dealing with normalised sheets which are subsequently subjected to 20% cold-rolling elongation, the evidence obtained from the Erichsen test would seem to be all that is needed. Nevertheless, the authors still feel that a more reliable method is required, and if one could be devised it might show differences in the behaviour of material in its commercial drawability which perhaps would not be anticipated from other considerations.

From the experimental data and evidence obtained with this series of observations, there is every indication that one important conclusion can be drawn. It is that, so far as can be estimated from a consideration of the tensile properties, the pressing qualities of a sheet obtained by first normalising and then cold-rolling to the extent of 20% extension, followed by annealing at temperatures as low as 700–750° C., should be at least as good as can be obtained by annealing at 950° C. The Erichsen test results, for what they are worth, lend support to this view.

Normalised Specimens Cold-Rolled to 40% *and* 100% *Elongation.*

The main features of the curves obtained by plotting the results for these two series of experiments are very much alike, and can be described together. Indeed, they are in many ways similar to those of the 20% cold-rolling elongation series, which have already been discussed. Differences in some important points of detail were observed with regard to those with 20% cold-rolling elongation, which justified dealing with them separately. The data for those given 40% and 100% elongation are plotted in Figs. 16 and 17. From these it will be noticed that the changes in the ductility occur at about the same annealing temperatures as for the 20% series. At

the same time, it is evident that the elastic limits do not fall to such low values in these two series, after annealing at temperatures above 600° C., as was the case for the corresponding samples which had been extended 20% in rolling. For example, the elastic limits, for the two directions of rolling, after annealing the 40% samples at 600–900° C., lie between 9·0 and something over 10 tons, with a tendency to be nearer the higher figure.

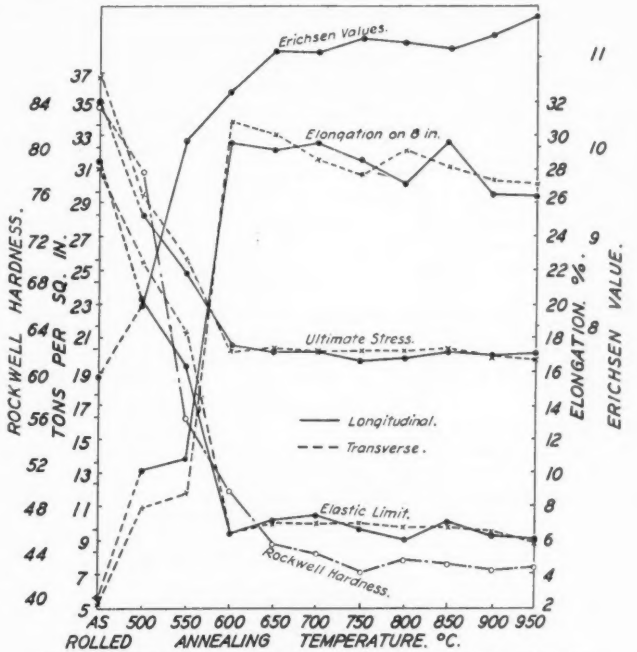


FIG. 16.—Sheets Normalised before Cold-Rolling; 40% extension.

With 100% cold-rolling elongation still higher values are obtained, after annealing within the same range of temperature—namely, elastic limits of from 10·7 to 13 tons. For the 20% series, on the other hand, the figures were 7·5–8·2 tons.

For the same range of temperature, only small differences were observed in the ultimate stress values, but these were definitely in the direction of the 40% and 100% being higher than the 20% series.

With regard to the elongations in both series under review, these show a general tendency to decrease as the annealing temperature

is raised above 600° C. At this stage, it would be unwise to attempt to differentiate between the effects of 20, 40, and 100% cold-rolling extension upon the elongations obtained after annealing at temperatures above 600° C., but reference will be made to this in the general discussion.

Microstructures.—It is unnecessary to reproduce the structures of both the series now being described. They appeared much the

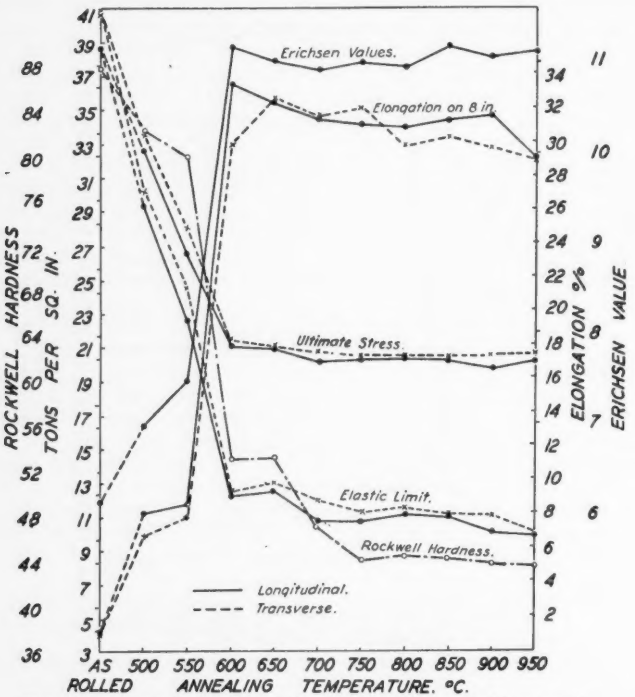


FIG. 17.—Sheets Normalised before Cold-Rolling; 100% extension.

same for each, after annealing at similar temperatures, the only noteworthy differences being of such a nature as to be readily understood from a verbal statement. A selected number of photomicrographs, taken from the specimens which had been elongated 100% during rolling are depicted in Fig. 30 (Plate X.). From an examination of these, it will be noticed that the severely deformed ferrite crystals, resulting from the cold-rolling, undergo complete recrystallisation after annealing at 600° C., and this results in the

production of extremely small crystals of ferrite. On raising the annealing temperature, there is a tendency for these crystals to grow, but even at the higher temperatures this is not particularly marked. There can be no doubt that it is on account of the presence of these very small ferrite crystals that one obtains such relatively high values for the elastic limits and yield points, even after annealing at temperatures between 600° and 900° C.

The same remarks apply, but in a somewhat lesser degree, to those samples which were extended 40% in the cold-rolling and afterwards annealed at 600–900° C., the only difference being that, in these instances, the elastic limit values were not so high because the ferrite crystals were rather larger than those just referred to. By extending this line of reasoning and comparing the crystal sizes in the photomicrographs in Fig. 29 with those in Fig. 30, it will be evident that the low elastic limits and yield points obtained are associated with the presence of larger ferrite crystals. Further confirmation of this view can be obtained by referring to the data and microstructures of those specimens which were subjected to 5% and 10% extension in cold-rolling. In these instances, however, the effects are even more intensified, because of the presence of abnormally large crystals of ferrite.

Erichsen Tests.—The results obtained from this test, for the 40% and 100% series are plotted in Figs. 16 and 17. Apart from the fact that the values obtained are consistently good, after annealing at all temperatures above, say, 650° C., it would be difficult to make any further reliable deductions at this stage.

It is interesting to note, however, that the Erichsen values obtained from the specimens that were cold-rolled to give 20% extension, and annealed at temperatures of 650–750° C. are slightly better than those which were more heavily cold-rolled and annealed at the same temperatures. Whether this is real, and due to a more suitable crystal size or to some unknown factor, it is at present impossible to say.

Experiments with Material which was Box-Annealed, Previous to being Cold-Rolled.

Since it is often the commercial practice to box-anneal steel sheets in quite large bulk, the authors thought it might prove of interest, more especially to manufacturers, to examine the effects of varying degrees of cold-rolling and subsequent annealing temperatures upon their properties. Quite apart from the possible practical significance of evidence obtained in this manner, it was anticipated that the results would serve to emphasise the important influence of the initial size of the crystals in the material upon the ultimate quality of the sheets; or, in other words, that the properties of the finished sheets, as obtained by box-annealing on the one hand and normalising on the other, are not necessarily the same when they are subsequently cold-rolled to a specified degree and annealed at a given temperature.

In considering the experimental results which are about to be described, it should be remembered that, in dealing with material which has been box-annealed, the ferrite crystals are not equi-axed, but elongated in the direction of previous hot-rolling.

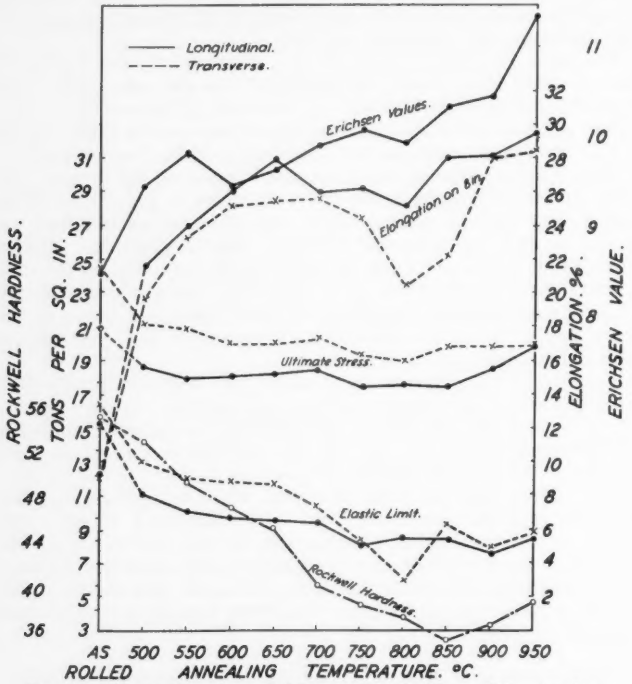


FIG. 18.—Sheets Box-Annealed before Cold-Rolling; 5% extension.

Box-Annealed Specimens Cold-Rolled to 5% *and* 10% *Elongation.*

These two series are being considered together; for, although the material used for the 10% series contained rather abnormally large ferrite crystals, and the results are thus thrown out of step in relation to the other degrees of cold-rolling, they do not call for separate detailed consideration. The results are plotted in Figs. 18 and 19.

In both instances the mechanical properties are relatively very poor, and in many respects similar to those already described for the normalised specimens which had the same degree of cold-rolling.

With the 5% series, there is a tendency towards ferrite crystal growth after annealing at medium high temperatures. This is

even more pronounced with 10% cold-rolling, with the result that abnormally low elastic limits are obtained after annealing at temperatures between 750° and 900° C. When this occurs, the corresponding ultimate stresses and elongations are on the low side. There is no doubt that sheets in the condition as revealed in both

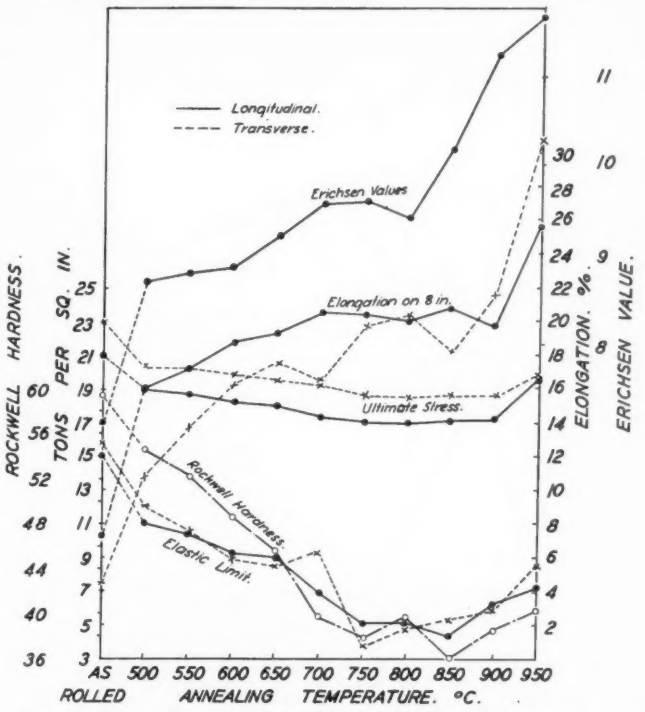


FIG. 19.—Sheets Box-Annealed before Cold-Rolling; 10% extension.

these series, after annealing at all temperatures below 900° C., would prove quite unsatisfactory for deep-drawing purposes. Typical representative structures of these two series are depicted in Figs. 31 and 32 (Plates XI. and XII.).

Box-Annealed Specimens Cold-Rolled to 20, 40, *and* 100% *Elongation.*

In view of the detailed description of the results for the normalised specimens for these degrees of cold-rolling, and the fact that the principal features are very much the same for the curves representing

these results, it will be sufficient to consider them together. The curves are shown in Figs. 20, 21, and 22. It will be seen from these diagrams that the elastic limits for each particular series, after annealing above 650° C., are generally lower than those obtained from the corresponding normalised specimens. This is due to the fact that, when recrystallisation occurs in the cold-rolled box-

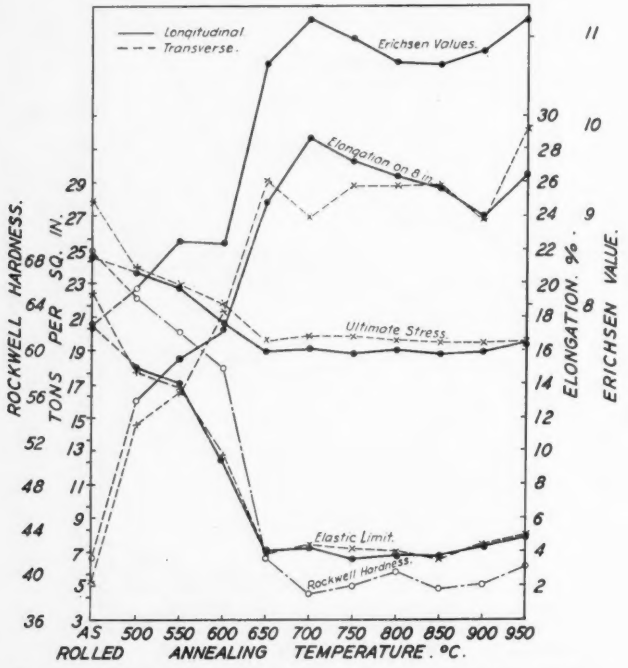


FIG. 20.—Sheets Box-Annealed before Cold-Rolling; 20% extension.

annealed specimens, the crystals that are produced are not as small as those which form under similar conditions in the previously normalised material, and this relative difference persists as the annealing temperature is further raised to above 900° C.

A very good idea of this and other structural changes, typical of these three series of experiments, can be gained from Fig. 33 (Plate XIII.) in which are depicted a few selected micrographs of the samples subjected to 100% cold-rolling elongation.

Summary and Conclusions.

When dealing with low-carbon steel, of the quality used in the present investigation, subjected to cold-rolling and subsequent annealing, the results indicate that the following general conclusions can be drawn.

Cold-rolling which gives an extension lying between 5 and 15%

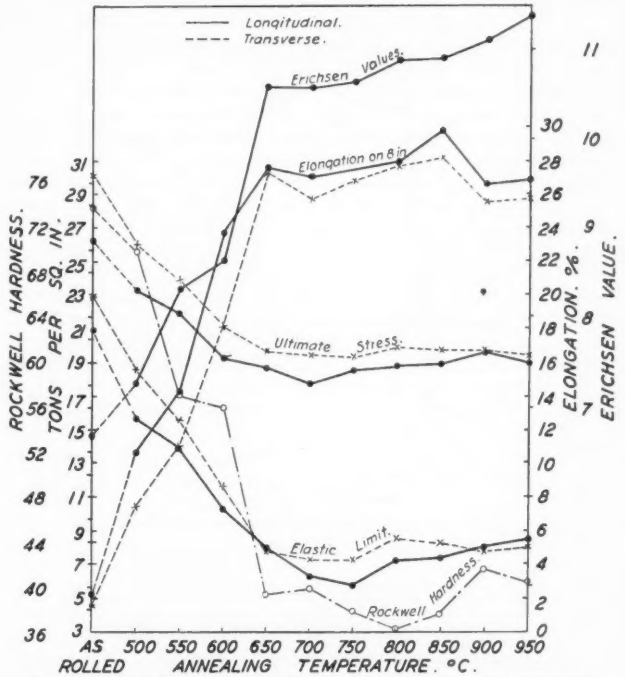


FIG. 21.—Sheets Box-Annealed before Cold-Rolling; 40% extension.

and annealing at any temperature below, say, 900° C., leaves the material in an unsatisfactory condition for drawing or pressing purposes.* The reason for this is that by these means the inner

* The authors feel it is necessary to observe, at this stage, that the critical range of cold-rolling in this instance is different from that which was observed in dealing with the thinner sheets in Part I. In the latter case, the lower range was certainly below 5%, whilst the upper limit at which complete recrystallisation took place was, say, 20% for specimens which had been normalised before cold-rolling, and 40% for those which had been box-annealed.

structure and mechanical properties are made unsuitable and would render the material incapable of undergoing a difficult pressing operation. Naturally, with annealing temperatures of below 650° C., the work-hardening produced by the rolling is only partially removed, the elastic limits and ultimate stress values being still much too high, and the elongations far too low. After annealing

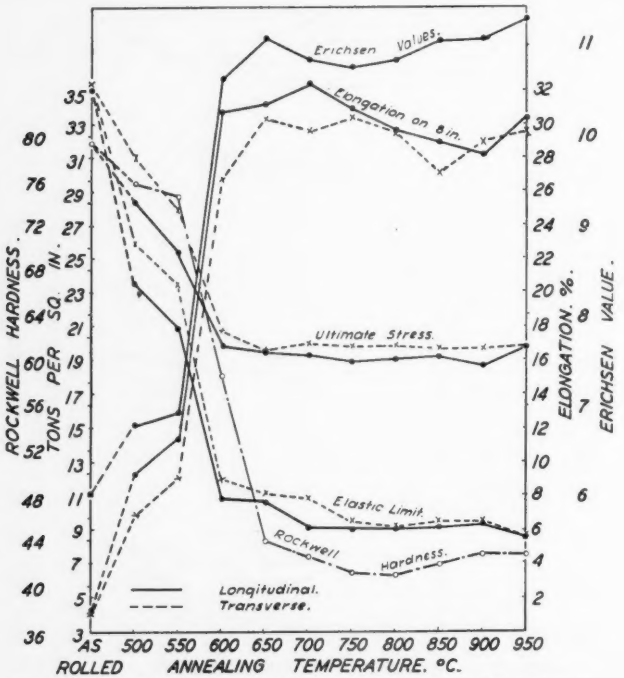


FIG. 22.—Sheets Box-Annealed before Cold-Rolling; 100% extension.

at 700° C. and upwards, the strain-hardening is removed, but if the temperature is below the A_3 point this softening is accompanied by excessive ferrite crystal growth. This is a most undesirable structure, because during deformation the differential flow which takes place on the slip or gliding planes within such crystals, causes a roughening of the surface of the finished pressing. Further, the mechanical properties of sheets containing these large crystals are unsuitable, the elongations being much too low, with an additional tendency to be erratic. Incidentally, it should be emphasised that

the presence of these large crystals of ferrite gives rise to abnormally low figures for the elastic limit and yield point. This is mentioned, not with the idea of suggesting that low values are in themselves objectionable, provided that the ferrite crystals are not too large, so much as to show that they can be used as an indication of the presence of such unduly large crystals. When dealing with steel such as is under discussion, if the elastic limit is below 6·7 tons per sq. in., it would seem reasonable to conclude that there are some ferrite crystals present which are undesirably large.

In carrying out the tensile tests on samples annealed after cold-rolling, evidence of plastic flow was seen on the surface of the test-piece on reaching the yield point. Those specimens which had been cold-rolled and annealed in the ranges which caused very marked crystal growth showed a roughening of the parallel section, the degree of roughening increasing with further loading up to the point at which fracture took place. In the specimens showing less uniform grain growth, the yielding occurred at several isolated zones and took the form of Luders lines, or stretcher strains of irregular shape, best described as curved bands, which gradually widened until the whole surface was slightly but uniformly roughened.

With test-pieces which, on the one hand, had recrystallised as a result of heavy cold-rolling and subsequent low-temperature annealing, and those which, on the other hand, had recrystallised by being heated above the A_3 change point, yielding occurred by the formation of a thin Luders line near the middle of the gauge length, or by the formation of two Luders lines near the shoulders. They were quite straight, and inclined at an angle of 40–45° to the axis of the specimen. Yielding continued with a gradual widening of the lines, until the whole surface showed a smooth but slightly frosted appearance.

It is of interest to note, at this stage, that the Rockwell test gives results which very closely follow the elastic limit values, and if material contains very large ferrite crystals it is possible to detect their presence by this test. When, however, these crystals are only in isolated patches, as sometimes happens, this method might fail where an elastic limit determination would not.

With normalised specimens which have been extended in cold-rolling by 20–100%, low-temperature annealing (*i.e.*, below 600° C.) will not entirely remove the work-hardening, and in consequence the material is unsuitable for deep-drawing purposes. At 600° C. and above, however, recrystallisation, as distinct from crystal growth, proceeds at a rapid rate, and the ductility immediately improves. The tensile properties finally obtained by annealing between 600° and 900° C. vary according to the particular degree of the previous cold-rolling. Thus, with the 20% series, the average elastic limit for the two directions of rolling is 8·0 tons after annealing at 650° C., and this figure becomes slightly lower as the temperature is raised, reaching 7·8 tons for 900° C.

With complete recrystallisation, resulting from annealing above the A_3 point, a normal elastic limit of 9·2 tons is obtained. With 40% extension, the elastic limits, after annealing at 600° C. and above, are consistently higher than those of the series just referred to, being from 9·4 to 10·2 tons, but falling to the more normal figure of 8·9 tons after annealing at 950° C. This tendency to high elastic limit values is even more pronounced in the 100% series; for example, with annealing temperatures of 600° and 650° C. the values are above 12 tons, showing a more or less general decrease as the annealing temperature is raised to 900° C., when it is 10·5 tons. These differences are due to the influence of the size of the ferrite crystals present. When crystallisation occurs at 600–650° C., the size of the ferrite crystals obtained diminishes as the amount of strain-hardening to be removed increases, and, within the limits of crystal size under consideration, the elastic limit increases with a decreasing size of ferrite crystal present. With the 20% cold-rolling extension, the crystal size obtained on recrystallisation at 650° C. is about the same as, or just a little larger than is produced by slow cooling from 950° C., and, in consequence of this, there is practically no further crystal growth by raising the annealing temperature. Hence the elastic limits are virtually the same for all annealing temperatures between 650° and 900° C.

With specimens which have been more heavily cold-worked, the crystals produced at the recrystallising temperature of 600° C. are unusually small, and definitely appear to grow as the annealing temperature is raised; in view of this, the elastic limit values are high for the low annealing temperatures, and tend to become lower with rising annealing temperatures. This is rather strikingly evident in the 100% cold-rolled series.

What has been said concerning the effects of varying ferrite crystal size upon the elastic limit of these three series, namely, 20%, 40%, and 100% cold-rolling elongation, applies to the ultimate breaking stresses. Here again, as would be expected, the higher values are obtained with specimens containing the smaller ferrite crystals, but the differences in this connection are not so great, after recrystallisation has taken place, as were observed in the case of the elastic limits.

Turning now to the effect of cold-rolling and annealing upon the elongation values, one finds :

(*a*) As would be anticipated, there is a very marked improvement in the elongation by annealing at and above temperatures at which recrystallisation occurs.

(*b*) So far as the ranges of cold-rolling that have been used in the present investigation are concerned, the highest elongation values have been obtained from the 100% cold-rolled series. Moreover, on comparing the results obtained after the various annealing temperatures, it will be seen that the highest elongations are obtained for, say, a temperature of 650° C.

With regard to the elongations on 8 in., including the fracture, there is a definite tendency for these to diminish as the annealing temperature is raised for the 100% series. This, however, cannot be said to apply to the general elongations, excluding the fracture, for, apart from the somewhat higher result obtained for an annealing temperature of 650° C., the values are in remarkably close agreement.

Speaking generally, the elongations on 8 in., including the fracture, for the 20% and 40% extensions by rolling are much the same for comparable annealing temperatures. There is, however, a greater and more consistent difference in the results obtained from pieces tested in the two directions of rolling in the former series, and a rather more definite trend for the values for 40% cold-rolling elongation to become lower with rising annealing temperatures. The general elongations of these two series of results do not appear to present any features of outstanding interest, apart from the fact that the best values are obtained by annealing at low temperatures when recrystallisation takes place. In considering the data obtained from the present investigation, the following question naturally arises, namely: What is the particular tensile property or combination of properties which determines the suitability of mild steel for deep drawing or pressing purposes?

Whilst a few tentative observations will be made on this later, the authors feel that, with the evidence at present available, it would be unwise to be dogmatic. Before a complete answer can be given to the above question, it seems necessary to have a reliable "drawing" or "pressing" test, which is capable of classifying material according to its capacity for drawing purposes, and of discriminating between supplies which are able, and those which just fail, to give satisfaction in the production of a very difficult pressing. With a machine of this kind, it should then be possible to correlate the drawing qualities with the mechanical properties and structure of the material, and determine the most suitable ranges of treatment for the commercial production of these properties, &c.

For reliable information to be obtained in this connection, it would seem most desirable that all the early experiments should be carried out on the same carefully selected raw material; the sheets should be made under carefully controlled conditions, and the heat treatments of the blanks carried out in a laboratory. It is hoped that the present work will prove to be one step in the direction of simplifying the fulfilment of such a scheme, because it indicates the ranges of cold-rolling and annealing temperatures that are most likely to lead to results of value, both from an academic and the practical point of view.

An extensive investigation of this aspect of the problem has been started for the Automobile Research Association.

Obviously the outstanding feature or property a material should possess for drawing or pressing purposes, is that of extensive plastic deformation before fracture.

The elongation of an ordinary tensile test up to the fracture, or the general elongation up to the onset of local constriction, is one measure of this; but, under these conditions of deformation, the movement which takes place at the crystal boundaries and within the crystals themselves would appear to be much simpler than that during a drawing operation when the material is being subjected to compression and bending stresses. When this is remembered, it seems well within the bounds of possibility that comparatively small variations in the size of the crystals present, which cannot be easily detected by tensile testing, might give rise to different degrees of work-hardening during pressing, and thus give results which are not in accord with tensile elongation figures.

Another factor, which must affect the importance that is attached to the elongation value from a drawing point of view, is the elastic limit, or alternatively the yield point. Of course this is recognised commercially, and maximum yield points for deep drawing steel sheets are specified. There can be no doubt that the relationship between the elastic limit or yield, and the ordinary elongation, plays an important part in determining the deep drawing ability of mild steel; more evidence is needed before the exact extent of this influence can be defined.

In the absence of any reliable method of measuring the capacity for deep drawing or pressing at the authors' disposal, they cannot draw any definite conclusions from their data in this connection. As a matter of interest, however, it may be mentioned that they have plotted curves for each series of experiments for the elongations minus the elastic limits, and find that the diagrams obtained in this way present many points of similarity to the Erichsen curves. There are, of course, points of difference, but how far these are due to uncertainties in the Erichsen test itself it is impossible to say. Needless to mention, this particular method of regarding the problem is of no use when considering specimens which contain abnormally large crystals of ferrite.

Acknowledgments.

The work which is embodied in the two investigations just described has been carried out for the Research Committees of the South Wales Siemens Steel and the Welsh Sheet and Plate Manufacturers' Associations.

The authors would like to take this opportunity of expressing their great appreciation and thanks to members of the above Committees, and particularly to Captain Leighton Davies, who is Chairman of each, for the valuable help and the stimulating interest and advice they have given throughout the progress of the work.

On behalf of the above Committees, they would also like to acknowledge the substantial financial assistance which has been given by the British Iron and Steel Federation towards this and other investigations.

In the conduct of the work itself, the Committee and the authors owe a deep debt of gratitude to Messrs. Baldwins, Ltd., for allowing the authors to carry out, in their works, the hot-rolling of the sheets for Part I., and even more to Mr. Gerald Michael, Managing Director of the Glynhir Tinplate Co., Pontardulais, for the extensive facilities placed at the authors' disposal in connection with the box-annealing, normalising, hot-rolling, and particularly the cold-rolling operations which were required for the work.

They would also like to indicate how grateful they are to Mr. O. J. Thomas for the very considerable personal help he rendered in all the work that was carried out at the Glynhir Works.

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DISCUSSION.

Dr. T. SWINDEN (Member of Council, Stocksbridge) thanked the authors for their paper. Apart, he said, from the detailed information contained therein, it must form the basis of the further work that was planned at Swansea on sheets and at Sheffield on strip for the Research Committee of the Institution of Automobile Engineers.

Principal Edwards, in introducing the paper, had reiterated the fact that as yet there was no test which would indicate the drawing properties of strip and sheet such as could be applied in the test-house or laboratory of the producing or receiving works. That was one of the main objectives of the research work of the Institution of Automobile Engineers, and was clearly a very desirable one.

There was one small criticism which he wished to make. Under the heading "Experiments with Acid Steel" the authors were careful to point out that, "Whilst open-hearth steel has been used for this purpose, it should be mentioned that any differences in the behaviour of the material in this connection depend more on the composition than upon the process of manufacture of the steel. In other words, the object in the present instance must not be regarded as an attempt to compare the two processes of steel-making, but merely to compare the effects of differences in the sulphur and phosphorus contents of the steels." In the conclusions at the end of Part I. of the paper, however, these were compared as acid and basic steels rather than as two steels of different composition. He mentioned that because it had become the fashion to compare in various ways acid and basic steels, and he thought it was important that no misconception should arise on that point.

There was one further point which he would like to emphasise, and it was one to which Principal Edwards had referred at the end of his introduction of the paper, namely, the important influence of finishing temperature in hot-rolling, and the consequent degree of "cold-working" effected in the hot-rolled material. He had only very limited experience of sheet, but very definitely in the case of strip it was possible to obtain all the grain growth one desired by low-temperature annealing if the finishing temperature of the strip had been low. The difficulties that were entailed with some of the older types of slower-running mills were entirely obviated with the more modern type of strip mill, but it did at one time mean that all soft strip had to be high-temperature annealed or given subsequent extra cold-rolling before any low-temperature annealing could be carried out. That point was not always fully recognised.

He had no desire to express any disagreement with the main data presented. They represented a great deal of very carefully conducted work, and he hoped it would have the result of urging forward the consideration of the very important problem of developing some correlation between the properties of the material that could be determined in the laboratory or test-house of the producing

works and the actual behaviour of the sheet or strip in the user's works.

In conclusion, he would like to say how valuable it was that Principal Edwards, in common with the heads of similar institutions, should bring into collaboration his students. He had a personal interest in mentioning that, because one of the co-authors of the present paper joined his staff twelve months or so ago, and he felt sure that the excellent work which that gentleman was doing now was directly the result of the training he had received in research of the kind now under discussion.

Captain Leighton Davies had hoped to take part in the discussion, but had been compelled to leave the meeting. Captain Davies had asked him to express his very high appreciation of the paper. He did not know what else Captain Davies would have said, but probably it would have been on the lines of suggesting that, after all, the industries of South Wales were not quite so backward as might have been implied on several occasions.

Professor J. H. ANDREW (Sheffield) said that second-rate work was never associated with the name of Principal Edwards; something really good was always to be expected from him. The data which the authors had given would not only be extremely valuable to those interested in the scientific aspect of sheet rolling, but would also be invaluable to industry. The leading feature of the paper was that the results confirmed one another; whether the authors reduced by 10, 20, 30, or 40%, all the changes which they obtained gave very similar or corresponding figures. He was delighted that Principal Edwards had seen fit to bring in his work on single crystals and on the study of crystallisation, because he thought it showed very clearly that, if they were to get to the bottom of the practical operations involved in sheet rolling, they would have to pay even greater attention to scientific principles than was done at present. He thought the authors would agree that it was undesirable to be content with applying the microscope alone. Some work which Dr. Rodgers was doing in his laboratory had shown that when a metal was cold-worked there was preferential orientation along a certain axis—that of rolling. That preferential orientation reached a maximum at a position between the surface and the centre of the strip, which varied with different degrees of reduction, but the interesting feature was that it was not destroyed by normalising, but still persisted. That was borne out to some extent by Fig. 10 of the paper, which showed a relatively large difference between the transverse and the longitudinal tests. The micro-examination would presumably reveal more or less equi-axial crystals in that material. There must, therefore, be some explanation for the difference in the tensile properties in the two directions of the strip, because he believed that the strip had been rolled in both directions during its process of manufacture.

He was very pleased to find that the authors had made an attack—a mild one, it was true—on the method of box-annealing. Had anyone determined the exact temperature of the centre of such boxes? It seemed an impossibility.

From the curves correlating annealing temperature with degree of rolling it would be seen that in the case of the normalised treated specimens a temperature of 600° C. was sufficient, provided that the rolling had been 40%. A temperature of 600° C. was fortunately below that temperature which brought about the spheroidisation of the carbide, or the temperature which caused the carbide to migrate to the grain boundaries—a feature which readily arose at a temperature of 650° C. From that point of view alone, therefore, by keeping the annealing temperature down—which the authors had shown to be possible by drastic cold-rolling—not only did one obtain a correct crystal size, and a sheet with all the mechanical properties desired, but one prevented this dangerous segregation at the grain boundaries.

Finally, he would like to know whether the authors could explain why phosphorus prevented the sticking of the sheets. He had asked at least a dozen people, and they had given him different explanations, so that he would like to hear what the authors had to say on the subject.

Professor THOMAS TURNER (Hon. Vice-President, Leatherhead, Surrey) said Principal Edwards had referred to the necessity for an improved test for the working properties of thin sheet metal. Everyone was, of course, familiar with the Erichsen test, which had the great recommendations of simplicity and rapidity; but it was not really trustworthy in many cases. Since the manuscript of the present paper had been received, a paper had been communicated to the Institute of Metals with reference to an improved test for sheet aluminium. It was found, for example, that the drawing qualities of sheet aluminium varied according to the temper, and that it was not the softest aluminium which possessed the best drawing qualities. The test was in the nature of a double cupping test. It was a very simple test, almost as simple as the Erichsen test itself; but it differentiated on account of the double action in its cupping. The authors of the paper referred to were Dr. Gwyer and Mr. Varley, who were well known in connection with work on aluminium. It did not follow, of course, that a test which had been proved in practice to be suitable for aluminium would also be suitable for mild steel; but at all events he suggested that it was an encouraging direction for progress, and if it were possible to have a simple test which would be better than the Erichsen, and not much more trouble, it would be a great advantage.

Mr. J. C. ARROWSMITH (Headington, Oxford) congratulated the authors on the comprehensive manner in which they had treated a

problem which was one of growing importance to the producers of deep-drawing sheet steel. Whilst some of the experimental work must have been done already in the research laboratories of the large sheet producers in America and on the Continent, where the heavy cold-reduction method of producing sheet had been carried on for some time, the results, as Principal Edwards pointed out, did not appear to have been published, and the authors had done a real service to the industry in Great Britain by attacking the subject in so thorough a manner and presenting the results to the Institute.

It was a matter of considerable satisfaction to find that the authors turned to the tensile test, and particularly to the tensile test employing the long-gauge-length type of test-piece, as being probably the most useful indication of the drawing properties of sheet steel. Indeed, the limitations of the Erichsen test had been shown up in no uncertain manner in the correlated results given in the paper.

On the penultimate page of the paper the authors suggested that the percentage elongation, the yield point, and the crystal size all had a definite bearing on the drawing properties of the material, and this was found to be the case in practice. He had made comparisons between the practical results obtained in the press-shop and the tensile tests obtained in the laboratory, and had found that it was possible to set approximate limits for the three values mentioned. Up to the present, however, the majority of the material which had been used in the plant to which he referred had been manufactured by the process of hot-rolling, and latterly this had been followed by normalising, pickling, and cold-rolling to improve the surface, and then a final low-temperature box-anneal. In connection with that final low-temperature box-anneal, which had been carried out at a temperature in the region of 600° C., it would have been interesting to have some more information on the completeness of the removal of cold-work at that temperature in sheets which had been extended only, say, 2% in the cold-rolling. The sheets which he had been receiving had been box-annealed in the works for, say, 24 to 48 hr., which was a very much longer time than any mentioned in the paper. If the removal of cold-work at that temperature, even after so long a time, was not complete, there was then a possible source of variation in the properties of the material. In this there might also be a clue to the difference in elongation which was observed between the normalised sheet and the heavily cold-reduced sheet which had been annealed at a lower temperature.

The conclusion which was most strongly suggested in the present paper was that the sheet produced by heavy cold-rolling followed by low-temperature annealing was possibly superior to the normalised sheet so far as drawing properties were concerned, but one aspect of the situation which had not been touched upon, except very lightly, was the question of stretcher strains.

In order to prevent stretcher strains from appearing in the

parts of the pressings which were stretched only just beyond the yield point, the fully annealed sheets must be subjected to a certain degree of cold-working, which was carried out either by cold-rolling in the sheet mill or by roller-levelling in the pressing plant with special roller-levellers designed to give drastic bending of the sheet. Heavy cold-reduction followed by annealing at 650° C. tended to produce a smaller grain size than hot-rolling and normalising with a suitable temperature gradient, and the smaller the grain size the more difficult it was to prevent stretcher strains. The limited experience which they had had up to the present with the heavily cold-reduced type of sheet indicated that, even where the grain size was approximately the same as that in the hot-rolled and normalised sheet, the heavily cold-reduced sheet was more difficult to deal with in regard to stretcher strains. After heavy cold-rolling and annealing, the sheets were in such a dead soft condition that it was almost impossible to pass them through an ordinary staggered-roll roller-leveller for flattening purposes without kinking them or causing corrugations in them, so that it was practically necessary to cold-roll the sheets slightly after the annealing operation. But, even when they had had a slight amount of cold-rolling, it was sometimes found that it was impossible to prevent stretcher strains.

With the roller-levellers, it had been possible in the past to relieve the sheet manufacturers from all responsibility for stretcher strains in the pressings. It had been possible to use sheets which had received no final cold-rolling after the final low-temperature annealing operation. The advantages of being able to do that had been twofold : It had been possible to make use of the full ductility of the material, and there had been no age-hardening of the material if kept in stock for a time. If it was not possible to prevent stretcher strains in the same way in the case of the heavily cold-reduced sheet, the onus for stretcher strains would of necessity return to the sheet manufacturer, and there would be mutual difficulties with regard to the ageing of cold-rolled sheets in storage.

It also appeared problematic at the present time whether these heavily cold-reduced sheets which had been low-temperature annealed and finally cold-rolled adequately to prevent stretcher strains would be any better with regard to drawing properties than the hot-rolled and normalised sheets which it was possible to take in the fully annealed condition. When considering the high values for percentage elongation shown in Tables VIII. to XXI. it must be realised that in this condition the material would be subject to severe stretcher strain on pressing, and a fair amount of cold-work would have to be done on that material before it would be useful for pressings in which stretcher strains must be absent, as in the outer panelling of a motor-car body.

There were one or two other points in connection with the experimental evidence in the paper on which he would like to touch. In connection with the theoretical aspect of stretcher strains, the

remarks made by the authors in the " Summary and Conclusions " to Part II. suggested that only in the case of the tensile test specimens showing less uniform grain growth were stretcher strains noticeable during the test. It had been his experience that a polished tensile test-piece of any mild-steel sheet in the fully annealed condition, regardless of uniformity of grain size, exhibited those markings as soon as the yield point was reached. It was rather difficult to see them at times, but if the test-piece were polished with fine emery before making the test on a fully annealed sheet, one would generally see those markings develop as soon as the yield point had been passed, regardless of uniformity of crystal size.

The statement was also made that the location of the first stretcher strain to be formed varied with the heat treatment to which the material had been subjected. The authors found the first stretcher strain to appear sometimes in the centre of the test-piece and sometimes at the ends of the test-piece. He had observed those stretcher strains appearing in the test-piece as the tensile test had been carried out, but he had never seen them appear in the centre of the test-piece first, but always at the ends of the gauge length, and one would expect that their initiation would be controlled by the distribution of stress in the test-piece, and that they would appear at the portions of the test-piece where the stress was highest. That being the case, given uniformly heat-treated material and the same methods of testing, one would expect them always to appear in the same place. On the other hand, if the conditions in which the heat treatment of the test-piece had been carried out in the laboratory had been such as to produce a slight gradient in softness in the test-piece gauge length, one might expect that they would start at the softest point in the gauge length. He would be very interested to have the authors' explanation of the difference in location of these initial stretcher strains.

CORRESPONDENCE.

Professor W. R. D. Jones (Cardiff) wrote that the paper embodied a very large amount of data, much of which was bound to affect future developments in the methods of production of sheet steel.

He was doubtful if the motor-car industry really needed sheets possessing almost flawless surfaces and at the same time physical properties, such as ductility and toughness, that would permit of maximum drawability, as suggested in the introduction to Part II. He granted that there might be a few instances where both these properties were necessary, but in very many cases they were not. For example, a flawless surface was necessary for a body sheet, but was not so essential for an oil-sump pressing, which required a sheet that would give the deepest possible drawing properties, whereas

parts such as body panels or mud-guards were not subjected to anything like the same depth of drawing. A rimming steel was ideal for producing a sheet with a good surface, but the quality of the rim was produced at the expense of the core, which was more likely to contain segregates which might decrease the drawability.

The paper showed definitely that to control the grain size it was necessary to regulate the amount of deformation and the temperature of heat treatment, and the conclusion was reached that with heavy cold-rolling a re-annealing at 600–650° C. was to be preferred to a complete annealing above the A_3 point, provided the grain size prior to cold-rolling was correct. That would be generally accepted, but the interesting part of the work was the comparison between pre-normalising as against pre-annealing before the cold-work, *i.e.*, if the grain size was correct—and it did not matter much how it was obtained—then it would give a good product by heavy cold-work followed by annealing at the lower temperatures, which were certainly more practicable from a works point of view. The mechanical properties shown in the graphs confirmed an opinion that the normalising treatment would result in a sheet which did not show such directional properties as the pre-annealed, but the difference, although both structures might seem to consist of more or less equi-axed grains, would be shown in a more striking manner if the microstructures of corresponding normalised and annealed specimens were analysed by the graphical method developed by R. G. Johnson. The effect of grain size could be traced back further. It was safe to say that ultimate grain-size control was affected by the grain size of the metal in the as-cast condition, and this would depend on careful control of the many factors involved in making the steel, such as, for example, the casting temperature and the choice of deoxidiser, which would have an effect not only on the grain size, but also on the gas content and the nature of the gas left in the metal.

He would like to ask whether the banded arrangement of the pearlite seen in some of the photomicrographs (in Part II.) was formed as a result of the heat treatment, or whether it was present in the bars before the experiments were commenced? It seemed to be more pronounced in the specimens which had been pre-annealed than in those which had been pre-normalised before cold-working. The presence of pearlite in this form in sheets caused many irritating difficulties in fabrication processes. It certainly seemed that directional properties (as seen from the photomicrographs) were more pronounced in the as-rolled and also in the subsequent annealed conditions if the material had been pre-annealed. This banding and directionality might be due to either (or both) the slower cooling during pre-annealing when compared with pre-normalising, or to the fact that the mechanism of recrystallisation at temperatures below A_1 was bound to be affected more by an inherent directionality, which could not be such an important factor if normalising, *i.e.*, heating to above A_3, were carried out. This might apply even more

strongly if the final operation after cold-work were box-annealing and not normalising.

Although the paper was not concerned with normalising as a final operation, he would like to ask the authors whether they considered that a final normalising process would not give better results still. In works practice the present-day normalising furnace, with its controlled atmospheres and almost automatic working, would give a product of finer grain size which was very uniform, and it would therefore behave better in severe drawing operations and would give a deeper depth of draw than would material finally box-annealed. This normalised material would not be so liable to the presence of thin embrittling films of cementite at the crystal boundaries. In order to get a grain size suitable for very deep drawing, *i.e.*, about 1100–1500 grains per sq. mm. in material of the composition given in Part II., normalising was necessary for the ordinary present-day steels used in Great Britain.

One of the many useful points in this paper was the evidence of the greater usefulness of the tensile test over the Erichsen test, and a correlated indication of the limits of the latter. This was shown in the conclusion given on p. 144 P that material giving good Erichsen values and the tensile properties shown in Fig. 11 would possess poor drawing properties; the evidence was at once apparent on examining the microstructure (Fig. 28). He would have liked to have seen figures for the reduction of area as well as elongation, as the former probably gave a better indication of the ability of the material to withstand plastic deformation. He would like to suggest that the combination of tensile properties which would give an indication of the drawability would be the elastic limit and reduction of area, and a material which possessed a low elastic limit combined with a high reduction of area would flow under (moderate) stresses if applied relatively slowly.

Mr. A. Allison (Sheffield) wrote that the paper by Principal Edwards and his co-workers was a worthy addition to the series of researches produced at Swansea. Although some of the information recorded had been vaguely understood by those connected with cold-rolled steel, the authors had presented a systematic record of great value, particularly as regards precise testing.

In Part I. the authors had dealt with material 0·013 in. thick for a special purpose, but the information was useful in a wider field, because presswork steel was supplied down to 0·008 in. thick, and it had been found extremely difficult to correlate tests with service behaviour in this range.

Referring to the experiments with acid steel described in Part I., it appeared to him that the silicon content of the steel used was very low for acid steel, although the analysis had not had any unexpected bearing on the result.

Part II. covered probably the widest field in presswork steel,

and for that reason he would like to make a mild protest against the insistence that the research was directed mainly towards body sheets, because these were only one of a vastly larger number of pressings, and problems connected therewith.

The effect of normalising prior to cold-rolling and annealing was very striking, and confirmed some experiments carried out by the writer's firm some years ago.

It was also very interesting to find that the elastic limits after 20%, 40%, and 100% reduction were 8 tons, 10 tons, and 11 to 13 tons and that this was connected with the drawing properties.

The authors, in attempting to answer the difficult question as to what combination of properties it was which determined suitability for deep drawing, had studied the physical properties of the material. He would like to make a suggestion from another angle. In the course of examining a wide range of shapes and sizes of pressings, he had been led to think that the physical properties must vary with the size and shape. For example, a flat piece of steel was frequently pressed into a three-dimensional article with little, if any, loss of gauge, whilst sometimes the material was drawn with considerable loss of gauge, so that the observation given in the " Summary and Conclusions " to Part II., that " the outstanding feature or property a material should possess for drawing or pressing purposes is that of extensive plastic deformation before fracture " was only true in some cases.

He felt, also, that in certain cases a higher elastic limit with a moderate Erichsen value was required, and that the excellent properties indicated in Fig. 15 would for some purposes be less suitable than material with a higher elastic limit and lower Erichsen value. He had in mind pressings of rectangular shape, and fairly large in span and depth, in which it seemed to him that a high elastic limit was required to enable the material to be pulled to the bottom of the die without rupture. He would like to ask the authors if they considered that an Erichsen machine with autographic indication of the force required to make the bulge would be helpful. The more exact measurement of the elastic limit and its application to deep drawing quality was particularly valuable to the industry.

Mr. J. H. WHITELEY (Consett, Co. Durham) wrote that it would be generally agreed that the authors had carried out a valuable and much-needed piece of work. The combined effects of rolling temperature and heat treatment on steel sheets and thin plates formed a subject which had long wanted systematic investigation, and, notwithstanding the excellence and comprehensiveness of the work described in the paper, there was, he thought, room for more of the same kind. Two conclusions stood out prominently, *viz.*, the importance of grain size in the Erichsen test, and the fact that the greater the degree of cold-working the more readily was its effect removed by heating above 600° C. The influence of another factor on

the results did not appear to have been considered, and that was the condition in which the carbon existed. In general, more pearlite should be present in normalised than in box-annealed material. This was well seen in Figs. 24 and 25; no pearlite was visible in the box-annealed steel, whereas a considerable amount had evidently been formed in the normalised sheets. Possibly, as the authors indicated, some decarburisation in the former contributed to this difference, but, in any case, it seemed likely that such variations in the microstructure would be reflected in the test results. With this in mind, the writer had examined them carefully, and it did indeed seem as though certain differences could be attributed to the state in which the carbide was present.

Take, for example, the tensile figures at 40% extension. Averaging the four results obtained at 500–650° C., the normalised samples were 2 tons higher than the box-annealed, whereas the difference between the two sets of four results obtained at 700–850° C. was on the average only 0·8 ton. At 5 and 10% extension a similar comparison showed even wider differences, probably because less softening due to spheroidisation had occurred at 600–650° C. Now, since the carbide would be in the same condition in all the samples finally annealed above 700° C., it could be inferred that the higher results given by the originally normalised sheets at the lower temperatures were due, in part, to the presence in them of more pearlitic carbide.

A similar examination of the Erichsen test results also suggested that the manner in which the carbide existed had some influence. Here it was, of course, especially necessary to select extensions which did not induce abnormal grain growth in the final heat treatment. As an example, two series of average figures for the four sets of results between 500–650° C. and 700–850° C., respectively, were given in Table A.

TABLE A.

Material.	Cold-Rolling Extension. %	Average Erichsen Values.					
		Heat-Treated at 500-650° C.			Heat-Treated at 700–850° C.		
		Box-Annealed.	Normalised.	Difference.	Box-Annealed.	Normalised.	Difference.
Basic Steel, Part I.	40	5·73	6·86	1·13	7·45	8·20	0·75
	100	6·05	6·97	0·92	7·55	8·21	0·66
Acid Steel, Part I.	40	4·79	5·65	0·86	7·41	7·81	0·40
	100	4·94	6·45	1·51	7·56	8·01	0·45
Basic Steel, Part II.	40	8·69	10·0	1·31	10·73	11·12	0·39
	100	8·86	9·2	0·34	10·87	11·04	0·17

It would be seen that the differences between the box-annealed and normalised results were noticeably less at the higher ranges of

reheating temperatures than at the lower. The former could, he thought, be attributed to variations in grain size, the normalised sheets with the smaller grain giving the better figures. The extent to which the difference figures for the lower range were in excess of those for the higher could consequently be set down to the original condition of the carbide in the two cases ; it would seem as though the presence of pearlite in the normalised steels had improved the figures for the range 500–650° C. It was remarkable that spheroidisation between 600° and 650° C. did not appear to have affected the results. There was, however, another possibility which must be considered. Part of the energy expended in cold-working was liberated as heat, and part was absorbed by the material, but it could not yet be said with certainty that, for the same extension of a given steel in different conditions, the amount retained was always the same. A method which would estimate or even qualitatively indicate such possible variations was needed in studying cold-rolling, and also cold-drawing and pressing operations. Perhaps he might be allowed to refer to one which many years ago he investigated in collaboration with Dr. A. F. Hallimond. It consisted in analysing the gases liberated when a 0·3 g. piece of the steel was dissolved in various strengths of nitric acid at 100° C. The procedure was certainly rather lengthy and tedious, but enough work was done to show that the method was capable of detecting quite small differences in absorbed energy. Among other things, it indicated that steel heavily cold-worked lost its excess energy at a lower temperature than when lightly cold-worked, and an example was given as an illustration.[1]

Finally, he wished to comment on the statement made in Part I., in the section dealing with the influence of varying times of annealing at different temperatures, that "the recrystallisation which accompanies the removal of cold work-hardening takes time." In this connection he had observed more than once, in working on other subjects, that there was a time factor in abnormal grain growth such as was seen in the micrograph depicted in Fig. 24, for 10% extension at 850° C. It seemed possible to avoid this effect in thin sheets by, so to speak, rushing the steel through the range of temperature at which it occurred, but whether such a method could be applied commercially was doubtful.

Professor E. H. Schulz, Mr. W. Püngel, and Mr. H. Kayseler (Dortmund), in amplification of the authors' work, drew attention to some further researches of various investigators, dealing with the same aspects and, to some extent, reaching the same or similar results. For instance, among others, the influence of cold-rolling and annealing on the mechanical properties of thin sheets and strip was critically examined by A. Pomp and his co-

[1] *The Iron and Steel Institute, Carnegie Scholarship Memoirs*, 1918, vol. 9, p. 54.

workers,[1] E. Marke,[2] H. Lassek,[3] and H. Kayseler;[4] the researches of J. Winlock and A. E. Lavergne,[5] and of C. A. Edwards and J. C. Jones,[6] were likewise directed towards the same end. The conditions for the production and testing of sheets for automobile bodies were investigated particularly by J. Winlock and L. Kelly,[7] by W. H. Graves,[8] and by W. F. McGarrity and H. V. Anderson.[9]

In the researches mentioned, the deep-drawing properties of the sheets were likewise determined by the Erichsen test, although the unsuitability of this test, which set up not so much a drawing stress but rather a complicated tensile rupture process, had often been pointed out. Attempts to discover a better testing method had, therefore, not been wanting. A very complete account of the deep-drawing tests proposed by various investigators was given by H. W. Gillet,[10] in which was included a very full summary of the English, American, German, and French literature on the subject.

Here, only two of the proposed testing methods would be discussed, namely, the deep-drawing expansion test of E. Siebel and A. Pomp,[11] and the wedge-drawing test of G. Sachs.[12] The last-named test appeared to be promising, if the stressing of the sheet could be made to resemble the conditions in practical deep-drawing. Whereas in the usual cupping tests the sheet was stressed to fracture in a single stage, in deep-drawing the sheet underwent increasing deformation in several consecutive steps—that was to say, the parts of the sheet which had already been deformed by one drawing process must be capable of further deformation in the later drawing stages. But an investigation of this step-wise increasing deformability was only possible if the sheet, during testing, was also submitted to not less than two consecutive stressings, which, further, must simulate, at least approximately, the deformation of the sheet in deep-drawing.

[1] A. Pomp and L. Walther, *Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung*, 1929, vol. 11, pp. 31–35.
A. Pomp and S. Weichert, *Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung*, 1928, vol. 10, pp. 301–316.

[2] *Archiv für das Eisenhüttenwesen*, 1928–29, vol. 2, pp. 177–184.

[3] *Mitteilungen aus dem Forschungsinstitut der Vereinigte Stahlwerke A.-G.*, 1934, vol. 4, pp. 23–38.

[4] *Mitteilungen aus dem Forschungsinstitut der Vereinigte Stahlwerke A.-G.*, 1934, vol. 4, pp. 39–82.

[5] *Transactions of the American Society for Steel Treating*, 1933, vol. 21, pp. 97–109.

[6] *Journal of the Iron and Steel Institute*, 1927, No. I., pp. 523–568.

[7] *Transactions of the American Society for Steel Treating*, 1930, vol. 18, pp. 147–178.

[8] American Society for Testing Materials, Symposium on Developments in Automobile Materials, 1930, Mar. 19, pp. 18–27.

[9] *Transactions of the American Society for Steel Treating*, 1933, vol. 21, pp. 119–139.

[10] *Metals and Alloys*, 1931, vol. 2, pp. 214–222.

[11] *Mitteilungen aus dem Kaiser Wilhelm-Institut für Eisenforschung*, 1930, vol. 12, pp. 115–125.

[12] *Metallwirtschaft*, 1930, vol. 9, pp. 213–218.

In Sachs' original wedge-drawing test, a wedge-shaped piece of sheet, as shown in Fig. A, was drawn through a flat die by means of the appliance illustrated in Fig. B. The wedge could be regarded

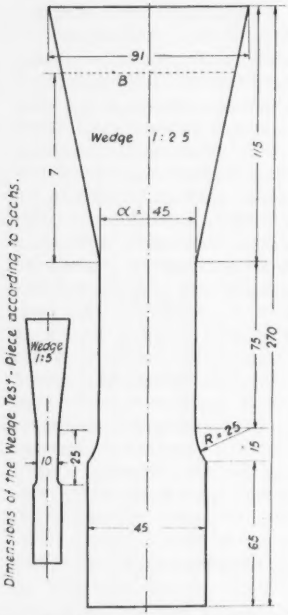

FIG. A.—Dimensions of the Wedge-Drawing Test-Pieces.

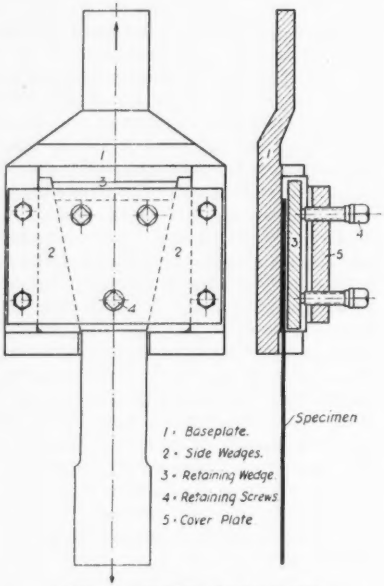

FIG. B.—Wedge-Drawing Test Apparatus.

as a circular section of a sheet disc, which, on deep-drawing, suffered similar deformation, in that the outer circumference of the disc was reduced to the circumference of the drawing punch; here, similarly, the broad end of the wedge was reduced to the same width as the narrow end. If the upper width of the wedge was too great, then the specimen broke on drawing. The maximum ratio of the upper to the lower width for which the specimen could be drawn without rupture should represent the greatest useful degree of deformation for the sheet under test—that was to say, the so-called "drawing limit" was determined, corresponding to that given by G. R. Fischer.[1] As, however, in the wedge-drawing test the specimen was stressed by only a single deformation process, this mode of testing also was unsatisfactory in its original form. J. C. Arrow-

[1] *AEG-Mitteilungen*, 1929, p. 483.

smith [1] had pointed out that in the wedge-drawing test the deformation conditions were similar to those during deep-drawing.

In order that the sheet should be tested under repeated drafts, a new method was developed at the Forschungsinstitut der Kohle- und Eisenforschung, G.m.b.H., in which the Erichsen and the wedge-drawing tests were combined (Kayseler, *loc. cit.*). In this method [2] a wedge-shaped test strip (Fig. A), with a lower wedge width of 45 mm., was drawn through the wedge-drawing apparatus (Fig. B) into a prismatic strip (Fig. C). In this way elongations—that is, deformations—increasing from the narrow to the broad end of the wedge were produced. Before the test, lines 10 mm. apart were scored on the wedge end—as in tensile testing—so that the deformation at all parts of the specimen could be measured accurately.

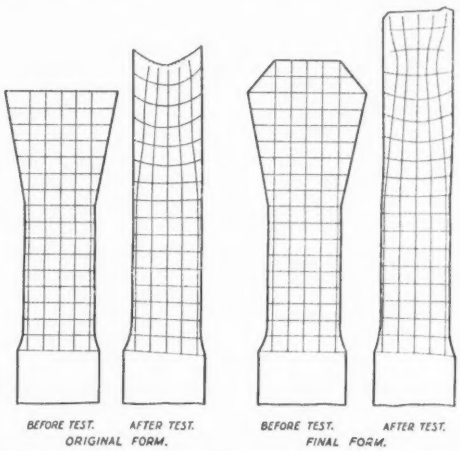

FIG. C.—Deformation of the Specimens in the Wedge-Drawing Test.

Erichsen tests were then made on the drawn wedge specimen with a small indentor, 13 mm. in dia., at several places corresponding to different degrees of deformation. (As the individual indentations must be separated from one another by a certain minimum distance, several wedge specimens were generally required in order to obtain sufficient values.) The depths of indentation so found were compared with the indentation depth of the undeformed sheet; the depth for the untreated sheet was made equal to 100%, and the values obtained after various degrees of deformation were expressed as percentages of this original value. On plotting them, diagrams

[1] *Metal Treatment*, 1935, vol. 1, pp. 117–120.
[2] British Patent No. 440,050.

such as that in Fig. D were produced. Here, for instance, the Erichsen value of sheet No. 4, after 26% deformation, still amounted to about 92% of that of the undeformed sheet, whereas, after the same deformation, the value for sheet No. 3 had already dropped to 55%—that was, after this deformation No. 3 was about 40% worse than No. 4. The normal Erichsen test gave an indentation of 11·9 mm. for No. 4 and 11·2 mm. for No. 3. This very small difference of only about 6% did not correspond with the behaviour of the sheets in practical deep-drawing; their actual behaviour corresponded much more closely with the marked difference between curves 3 and 4 in Fig. D.

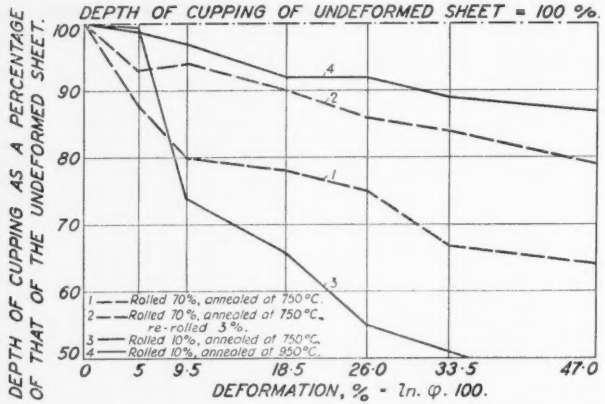

FIG. D.—Indentation Test on Drawn Wedge-Drawing Specimens.

As the valuation of sheets became the more accurate as the area of the deformed material which could be examined in the indentation test after drawing was increased, the form of the specimens was improved by reducing the broad end of the wedge to the trapezium shape shown on the right of Fig. C. As the line network in Fig. C showed, the greatest elongation (deformation) attainable for a given width of wedge lay at such a distance from the edge that an indentation test could be carried out at this spot. With the original test-piece (Fig. C, left) the theoretical maximum deformation was never reached, because of the drawing-in of the edge of the wedge and the commencement of wrinkling; further, as the Erichsen test must be made beyond a certain minimum distance from the edge, tests could only be made on specimens subjected to comparatively small deformations. The improved shape of test-piece had therefore extended considerably the testing range and had increased very much the reliability of the wedge-drawing indentation test. The utility

of the test described had been demonstrated practically in a number of cases. It was to be recommended, therefore, that this new test method should be taken into consideration in future comparative researches on deep-drawing sheets.

Mr. A. G. Robiette (Birmingham) wrote that he wished to record his appreciation of the authors' very valuable paper. It had come at an opportune moment, when many manufacturers of steel sheet and strip were contemplating the installation of modern rolling and annealing plant, and in this connection the inferences to be drawn from their work would prove particularly helpful in assisting manufacturers in their choice of equipment.

A case had undoubtedly been made out in favour of heavy cold-rolling followed by a low-temperature anneal, and if this was accepted, as it undoubtedly would be, he would like to ask the authors whether they would favour the retention of existing pack annealing methods involving conditions of heating which could not, by their very nature, conduce to uniform treatment of the material, or the adoption of continuous short-time annealing in single or small multiples of sheets in a protective atmosphere, and with a controlled heating time. This latter method of annealing was now being successfully and economically used for lengths of steel strip up to 24 in. wide, and its application was growing in favour, possibly to a greater extent in Great Britain than elsewhere. Not only would this method of annealing preserve the cold-rolled surface finish, but with hot-rolled material scale was removed by the reduction of the iron oxide, and pickling in many cases could be obviated. Moreover, if a true normalised structure was required it was simply a matter of raising the control temperature.

The writer had carried out an investigation on similar lines to those outlined in the paper but employing short-time annealing of single sheets by passing them through a continuous bright-annealing furnace. The total heating period varied from 1½ to 6 min. One interesting point which had emerged, and which in a general way was confirmed in this paper, was that the more heavily cold-rolled material was slightly harder and had a rather higher elastic limit than material which had had less cold reduction. In his experiments material which had received 60% reduction gave a Vickers hardness number of 101 to 104 on annealing in a range of temperatures between 650° and 900° C., whilst the same material cold-rolled 30% and annealed under similar conditions gave hardness figures of from 95 to 97. On normalising, the hardness figures became approximately the same for both materials. This effect was presumably due to the finer grain structure of the heavily cold-worked material. The material for the tests was deep-drawing quality steel.

The same effect as that noted above was also revealed in cold strip-rolling practice, and extremely heavy reductions of 60% and

upwards were often avoided owing to the fact that the material did not always conform to the hardness specification. He would like to ask the authors whether they considered that the higher hardness and elastic limit figures would materially affect the deep-drawing properties, assuming that other acceptance tests, such as elongation and Erichsen values, were satisfactory. It seemed to the writer that this heavily cold-rolled and annealed material, owing to its fine grain size, would have less tendency to develop stretcher strains.

He wished to raise one further point. In Part I., under " Annealing of Test Samples," the authors stated that the time required for a pack of sixteen sheets to attain a temperature of 500° C. was 3 min. This time seemed to be remarkably short, and he was wondering whether a figure of 30 min. was intended to be stated. In view of the poor rate of heat transfer by radiation at low temperatures it would be expected that the heating time to 500° C. (always assuming that the furnace was at 500° C.) would be considerably longer than the time to reach 950° C. Moreover, the short-time tests which he had done showed that a heating time to 500° C. of nearly 3 min. would be required for a single sheet of the thickness stated. He would be glad if the authors could enlighten him on this point.

AUTHORS' REPLY.

Principal EDWARDS, in verbal reply, said that in view of the lack of time he would confine his remarks to a very few points, and deal with the remainder in writing. He would first like to express, on behalf of his colleagues and himself, their sincere thanks for the observations which Dr. Swinden had made, and to thank also Professor Andrew for what he had said. It was not surprising that Professor Andrew, with his usual clarity, had noticed, and had indicated just as clearly, the limitations of certain points such as box-annealing. No one knew what the temperature in the middle of such boxes was. He thought that Professor Andrew's point with regard to the introduction of some kind of preferential orientation was quite definitely true. He would not attempt to give a dogmatic answer to the question of the influence of phosphorus in the prevention of " stickers," but he would venture to throw out a very mild suggestion. He thought that in all probability the presence of the phosphorus gave a totally different kind of film of oxide on the surface of the plates, and that oxide became more continuous and more capable of adjusting itself as the hot-rolling was carried out, thereby preventing the two metallic surfaces of adjacent sheets from coming in contact with each other.

He would like to thank Professor Turner for his remarks with regard to the double dishing test. They had now for many months been using the modified Erichsen double-cupping test, which he thought was an even greater improvement than the one to which

Professor Turner referred, and they hoped to obtain useful results; but the more their work proceeded the more complicated did they realise that the question became.

Mr. Arrowsmith's remarks were so extensive and so important so far as strain-hardening was concerned that it would be better to give a detailed answer in writing, when there would have been an opportunity of considering them more fully and carefully. He would like to say to Mr. Arrowsmith, however, that one of the most important features of the work embodied in the paper would ultimately be found to be that greater and greater care would have to be bestowed upon the low-temperature annealing. Personally, he would not be surprised if batch annealing for low-temperature cold-worked material slowly became obsolete, and some kind of continuous low-temperature annealing, in which the time of heating the material to the temperature could be easily controlled to any desired extent, were adopted; this would then make it possible to control some of the points to which Mr. Arrowsmith referred.

Principal EDWARDS and Mr. PHILLIPS wrote, in further answer to the verbal and written contributions, that they were pleased that their paper had given rise to such a useful discussion, which included so many interesting and valuable suggestions.

The point concerning the influence of phosphorus in the direction of preventing stickers in pack-rolling, raised by Professor Andrew, called for a little more elaboration than was given in the reply at the Meeting. In this connection they would like to state that nothing in the nature of a complete theoretical explanation could be given; it was interesting to note, however, that the presence of, say, 0·05–0·1% of silicon had much the same effects as that of phosphorus. As previously stated, it was thought that the beneficial effects of these elements were in some way associated with an alteration in the character of the oxide film that was produced on the surfaces, more particularly in regard to the ease with which it flowed during hot-rolling, thus maintaining a continuous layer of oxide between the metallic surfaces, and thereby preventing intermittent welding. In addition to this, however, there was the fact that two surfaces of metal containing these elements were not so easily welded together, even when they were perfectly clean.

Turning now to Mr. Arrowsmith's contribution, they would like to say that they regarded this as extremely useful, more especially from the point of view of the many important questions he raised, which deserved and would receive careful consideration as the authors extended the work they had in hand. They were definitely inclined to agree with Mr. Arrowsmith that, with low degrees of rolling the hardening effects were not completely removed by annealing at temperatures below the A_3 point. Broadly speaking, it could be stated that, as the amount of cold-rolling diminished, the annealing temperature must be raised to remove entirely the work-hardening. It was true that in the authors' experiments the

annealing times were not so long as those referred to by Mr. Arrowsmith, but they thought the above remarks were, nevertheless, applicable. It was, perhaps, desirable to mention that with low degrees of straining there was an increased risk of producing excessively coarse ferrite crystal growth with a prolongation of the annealing times at temperatures near to but below the A_3 point. They felt sure that, with sheets cold-rolled to the extent of only 2%, it could be stated that the hardening effects could not be completely removed by such low temperatures as 600° C., even when the time was prolonged to 48 hr. It was particularly useful to have the benefit of Mr. Arrowsmith's extensive and unique experience concerning stretcher strains. The authors did not feel they had sufficient knowledge about this interesting problem to discuss in detail the many important questions Mr. Arrowsmith raised in this connection. They would, however, like to say that careful attention would be given to them as the work now in hand on " strain age-hardening, &c." was developed. It would seem necessary to take into account not only such factors as straining, and annealing temperatures and times, but also due consideration would have to be given to the question of the chemical composition of the steel.

The authors did not feel called upon to answer in detail the doubts expressed by Professor Jones about the surface character and drawability of sheets used in the motor-car industry. These demands were being made by users of such material and, in most instances, it could be assumed there were very good reasons for making such rigid specifications. Though it might seem rather surprising, there was no doubt that a high degree of drawability was required for many kinds of mudguards.

Professor Jones was quite correct in suggesting that, in the case of a rimmed ingot, a greater degree of segregation of impurities towards the core occurred; this, of course, was inevitable from the very nature of the case. In other words, other things being equal, it was impossible to avoid an increased degree of segregation towards the core when a greater degree of purity in the rim was obtained. In spite of this, however, users were demanding rimmed steel for deep stamping. This rather clearly indicated what might have been anticipated, *viz.*, that the character of the material at and near the surface played a relatively more important rôle than that in the core.

The authors agreed that the evidence did seem to indicate an apparently greater degree of pearlite banding in the case of the slowly-cooled box-annealed specimens than in those that were normalised. What difference there was in this respect could, no doubt, be attributed to the slower rate of cooling in the former.

In answer to the question relating to the reduction of area at fracture, the authors did not include this in their observations, because it was practically impossible to obtain reliable data from relatively thin sheets such as were used in the present investigation;

further, they were inclined to the view that this factor could not have much bearing upon the drawability of the material. It must be remembered that the drawability was determined by the capacity of the material to undergo plastic deformation without fracture, whereas the reduction of area would seem to be more a function of the plastic properties while fracture was taking place.

The authors very much appreciated the kind observations made by Mr. Allison. They were pleased that Mr. Allison emphasised that the value of their investigation was not confined to motor-car body work; with this the authors entirely agreed. The points he raised did not seem to call for a reply, but they would be taken into account by the authors as their work was extended.

The authors were glad to have the interesting comments made by Mr. Whiteley, but felt that no useful purpose would be served by attempting to go into greater detail than had already been done by Mr. Whiteley himself. They agreed that there were three factors which contributed to the differences in the results obtained from normalised and box-annealed samples, *viz.*: The carbon content; the condition of the carbon; and the ferrite crystal size.

The authors would like to thank Professor Schulz, and Messrs. Püngel and Kayseler for drawing attention to their own work bearing upon the same problem, and took this opportunity of expressing their regret that they had unwittingly omitted to refer to this in the paper.

They would emphasise that, in the present work, an effort had been made to make a complete survey of the influence of varying degrees of cold-rolling and (what could be described as) the full range of annealing temperatures upon the tensile properties of mild steel which had previously been normalised on the one hand, and box-annealed on the other. Whilst the ultimate object of this work was to throw more light upon the problem of commercial deep-drawing qualities, this particular aspect of the investigation had only just been commenced, so far as the authors were concerned.

In answer to the first question put by Mr. Robiette, the authors would like to say that, in their opinion, the future tendency would be in the direction of annealing in small quantities under carefully controlled conditions, as distinct from the rather general method of to-day, *i.e.*, the use of heavy weights in large boxes. They would not care to commit themselves to a definite answer in reply to the rather hypothetical case mentioned by Mr. Robiette. Speaking generally, one would anticipate that, so long as the crystal size was not abnormally large, a low elastic limit was one of the primary needs for the production of a really deep draw. The reason for this statement was that the measure of drawability would be determined by the ease with which the material initially commenced to undergo plastic deformation. At the same time, it was just possible that, in special circumstances, the condition referred to by Mr. Robiette might prove advantageous. In this connection, the authors would

also refer to Mr. Allison's contribution dealing with this aspect of the problem.

Turning now to the question about the time taken to heat the specimens to the required temperature, the authors would like to confirm the statement that this varied from, say, 3 min. in the case of low temperatures, to 12 min. for, say, 950° C. They would, however, like to draw special attention to the fact that immediately the specimens were introduced into the furnace, the current was increased, and in this way the rate of heat input was raised until the temperature of the specimen approached to within a few degrees of that which was desired.

THE DISTRIBUTION OF SULPHUR BETWEEN METAL AND SLAG IN THE BASIC AND ACID PROCESSES OF STEEL MANUFACTURE.*

By E. MAURER and W. BISCHOF (School of Mines, Freiberg in Saxony).

Synopsis.

A brief review is made of previous publications relating to the behaviour of sulphur in steelmaking. The distribution of sulphur is studied from numerous operating analyses of the basic open-hearth process, disclosing the powerful desulphurising effect of manganese. The influence exerted by the silica content of the slag in the presence of varying amounts of lime is determined. These results are embodied in a composite diagram, and it is explained how the equilibrium conditions of sulphur distribution that can be read from it are modified if larger contents of magnesia, alumina, and phosphoric acid are present in the slag or of phosphorus in the metal, or by changes in temperature. The behaviour of sulphur in the acid process is discussed in the light of certain reports on heats, which reveal a dependence of the sulphur distribution on the phosphorus content of the metal, but which suggest that this effect is not attributable to physico-chemical equilibrium conditions alone.

A.—Introduction.

It has been explained in detail in a paper by E. Maurer and F. Bischof [1] that the factor which governs desulphurisation in the open-hearth process lies in the gaseous phase, and these workers have already determined the relationship between the sulphur content of the gas and that of the steel. In another work by the present authors [2] it was possible to show, by a mathematical treatment of the phenomena of desulphurisation and the combustion of the fuel gas, that desulphurisation by the gaseous phase takes place within certain definite limits according to the composition of the gas and the amount of excess air; for thermotechnological reasons these limits can never be exceeded. If, however, it is desired to carry the desulphurisation to a further stage, this can be done only by adjusting the distribution of sulphur between the metal and the slag—an adjustment which, as is well known, can be effected by removing and replenishing the slag so that the concentrations of sulphur in the slag and in the bath of metal respectively shall re-adjust themselves to the equilibrium conditions subsisting between the metal and the gas, as determined by the sulphur content of the fuel gas. It is the object of the present work to establish the laws governing this process.

* Received February 10, 1936.

In the basic open-hearth process the slag consists mainly of CaO and SiO_2, with the addition of some MnO and FeO, besides small quantities of P_2O_5, MgO, and Al_2O_3. It appears that sulphur is present in the slag in the form of CaS, FeS, and MnS, these sulphides changing to sulphates during storage, but at the moment it lies beyond the power of analytical technique to determine which of these sulphide combinations is in fact present. Throughout this work, therefore, the sulphur content of the slag will be denoted by " (S) " without regard to the form of combination in which it may happen to occur.

In the metal, however, the sulphur would appear to be present in the form of iron or manganese sulphide. Here again, as in the case of the slag, an analytical determination is not possible at present, and the sulphur content of the metal will be designated simply as " S."

As the presence of sulphur in steel is generally looked upon as obnoxious, methods of desulphurisation have long been the object of exhaustive studies. As early as 1902, H. von Jüptner[3] introduced Nernst's principle of proportionality, (S)/S, for the purpose of explaining the desulphurising reactions that may occur in the blast-furnace and in the open-hearth and basic Bessemer processes, and even at that time he attempted to determine the dependence of this relationship on the components of the slag and metal, but was not able to reach more than qualitative results. Neither was W. Heike[4] able to explain the effect of lime and manganese on the desulphurisation reaction by reference to the simple law of mass action. Finally, on these lines, H. Schenck[5] laid down mathematical laws, based on thermodynamical considerations, for calculating the effect of CaO, SiO_2, P_2O_5, Fe_2O_3, and FeO; making use of constants determined by experiment, these laws gave a good approximation to the actual conditions, but their complexity formed an obstacle to their application in practice. A. Diehl[6] attempted to relate the distribution of sulphur to the composition of the slag by approaching the problem from the standpoint of practical operation, making use of a relative quantity—the basicity of the slag, CaO/SiO_2—instead of the absolute quantities of CaO and SiO_2 present; he himself recognised the inadequacy of this method, and put forward the idea of a ternary diagram having corners corresponding to CaO, SiO_2, and FeO, but he was unable to reach a tangible result. Only recently a piece of pure laboratory research has been carried out by P. Bardenheuer and W. Geller,[7] but this has not yet been made capable of direct application to steel manufacture. Apart from all this work with reference to desulphurising reactions, a great many investigations based mainly on practical operation have been published[8-17] which cannot be further considered here, but none of these has led to other than qualitative results.

The literature of the subject contains no references to the dis-

tribution of sulphur between the slag and steel in the acid open-hearth process, and it is only known that operators of this process consider desulphurisation to be impossible. A thorough enquiry into this question will be made in a later section of the present paper.

B.—The Distribution of Sulphur in the Basic Process.

A large number of steel and slag analyses, as recorded in an earlier publication by the authors,[18] were available for the purpose of investigating the distribution of sulphur between the steel and slag in the basic open-hearth process, the use of this material being governed by the following considerations :

(1) In steelmaking, a condition of equilibrium is seldom attained during the progress of melting, as the factors which would determine that equilibrium are continually changing.

(2) During melting, the conditions of reaction tend to adjust themselves always in the direction of equilibrium, and this constant tendency is not interrupted either by the increasing temperature which attends melting or by changes in the composition of the slag caused by fusion of the lining and covering material.

(3) On the other hand, this continuous tendency is interrupted by the addition of fluxes and additions, which cause it to begin again from a new initial point.

In view of these factors, therefore, it becomes possible to ascertain in which direction the equilibrium lies by comparing two samples taken before and after a brief interval of time following upon the fusion of a charge, no addition of any kind being allowed to influence the natural shifting of equilibrium between the taking of the two samples. The partition coefficient (S)/S (as already applied by von Jüptner) for the first steel and slag sample is plotted as a point in a diagram, and the direction in which the partition coefficient of the second sample lies is indicated by an arrow.

As regards the effect of temperature, the final melting temperatures are in the neighbourhood of 1600° C., so that changes in the partition coefficient for sulphur tend from either side towards equilibrium at this temperature. The authors have maintained their assumption of a mean temperature of 1600° C. in spite of the attempts made in recent work [19] to introduce higher temperatures, for the latter have not been free from criticism.[20]

As the most important constituents of the slag, from the point of view of sulphur distribution, are its lime and silica contents, the partition coefficient (S)/S was fixed in relation to the silica content of the slag, while the lime content varied between only narrow limits (30–35%, 35–40%, 40–45%, and 45–50%). It is important also that other constituents of the slag, such as MgO, Al_2O_3, and P_2O_5, should be kept as low as possible.

It is also known, however, that desulphurisation is affected to an important extent by the manganese content of the steel, and in order to establish a proper interpretation of the procedure here adopted it is necessary that the influence of manganese should be eliminated beforehand.

(*a*) *Effect of Manganese on the Distribution of Sulphur.*—For each of the samples of steel and slag represented in the analyses with nearly the same lime and silica contents, the partition coefficient (S)/S was correlated with the manganese content of the steel at the time of sampling, and on plotting these results curves were obtained, as exemplified in Fig. 1. If the partition coefficient in the presence of

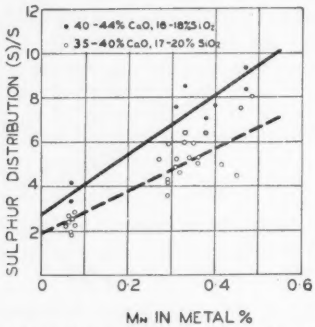

FIG. 1.—Influence of the Manganese Content in the Steel on the Sulphur Distribution.

manganese be denoted by (S)/S, and with 0% of manganese by $(S)/S_0$, the shape of the curves may be stated mathematically as follows :

$$\frac{(S)/S}{(S)/S_0} = 1 + 5{\cdot}0\,\mathrm{Mn}.$$

Here the coefficient 5·0, which corresponds to the slope of the curve, is found to fit different compositions of the slag fairly well, and it agrees also with the effect of manganese on the sulphur distribution in the presence of pure lower-oxide slags, as determined by Bardenheuer and Geller.[21]

According to the above, then, the improvement in desulphurisation brought about by the presence of manganese is very considerable. It seems impossible to attribute this effect entirely to the manganese content of the steel, and it is probable that the manganous oxide in the slag also plays a part. For similar lime and silica contents in the slag, a higher manganese content in the steel implies a higher manganous oxide content in the slag. The reason why the proportion of manganese in the steel is used instead of the MnO

content of the slag is because it is easier to determine the active or " free " MnO content of the slag from the manganese content of the steel than from the total MnO content of the slag.

(*b*) *Dependence of the Sulphur Distribution on the Lime and Silica Content of the Slag.*—In Figs. 2 to 7 the values of $(S)/S_0$ (that is to say, the partition coefficient (S)/S divided by the expression (1 + 5·0 Mn)) are correlated with the silica content within a limited range of variation of the lime content. Further, the available analytical material was classified as far as possible according to the magnesia content of the slag, samples with MgO contents of less than 5% being separated from those having between 5 and 10%.

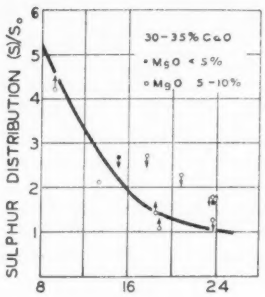

FIG. 2.—Relation of $(S)/S_0$ to the Silica Content with 30–35% CaO and 0–10% MgO.

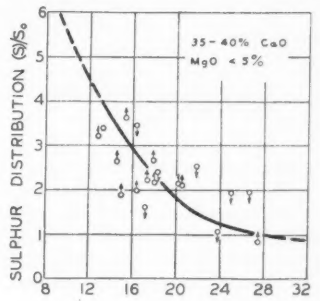

FIG. 3.—Relation of $(S)/S_0$ to the Silica Content with 35–40% CaO and 0–5% MgO.

In Fig. 2 the effect of silica in slags containing an average of 34·5% of lime is reproduced. The solid points refer to samples having less than 5% of MgO and the circles to samples containing between 5 and 10%. The arrows, with one exception, point towards the smoothed curve. The marked decrease in the partition coefficient $(S)/S_0$ that attends an increase in the silica content is made apparent by the trend of the curve, but for higher contents the influence of silica gradually diminishes.

Fig. 3 shows the condition for lime contents of 35–40% (averaging 38·8%) with MgO contents of under 5%, the result being a similar diagram to Fig. 2. It can scarcely be said that the points are widely scattered.

In Fig. 4 the $(S)/S_0$ values are shown for samples containing 35–40% (average 38·8%) of lime but between 5 and 10% of MgO, plotted against the silica content. Here again the scattering, as expressed by arrows pointing in the wrong direction, is small. For silica contents of less than about 18% the curve runs somewhat higher than for MgO contents of below 5% (Fig. 3).

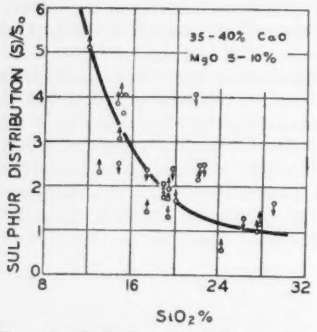

FIG. 4.—Relation of $(S)/S_0$ to the Silica Content with 35–40% CaO and 5–10% MgO.

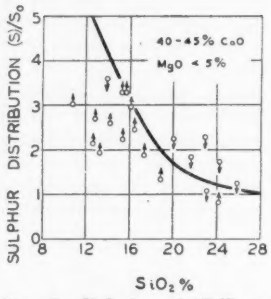

FIG. 5.—Relation of $(S)/S_0$ to the Silica Content with 40–45% CaO and 0–5% MgO.

In Fig. 5, further, the sulphur distribution is shown for slags containing 40–45% of CaO (average 42·9%) and MgO contents under 5%; here a perfect curve can be drawn.

The corresponding diagram for 40–45% of CaO (average 43·1%) with 5–10% of MgO is given in Fig. 6. Comparison with Fig. 5 does not disclose any effect due to the magnesia. The curves are in almost complete agreement.

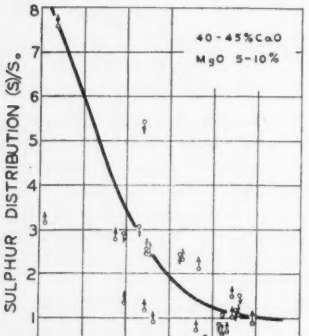

FIG. 6.—Relation of $(S)/S_0$ to the Silica Content with 40–45% CaO and 5–10% MgO.

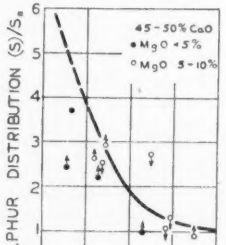

FIG. 7.—Relation of $(S)/S_0$ to the Silica Content with 45–50% CaO and 0–10% MgO.

Finally, Fig. 7 shows the ratios obtained with 45–50% of CaO (average 46·1%), both for MgO contents of less than 5% (solid

points) and for those of 5–10% (circles). Although the points corresponding to low MgO contents lie lowest throughout, no conclusion should be drawn from this fact.

The curves given in Figs. 2 to 7 offer the possibility of fixing quantitatively the equilibrium conditions for the distribution of sulphur between the slag and steel within the range of slag composition encountered in the open-hearth process. With this object a summary of all the foregoing results is presented in a somewhat different form in the fundamental diagram, Fig. 8, in which the

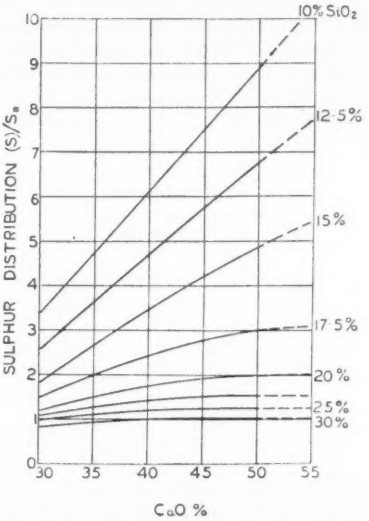

FIG. 8.—Summarising Diagram for the Relations between $(S)/S_0$, CaO, and SiO_2 for the Basic Process of Steel Making.

abscissæ denote the lime contents of the slags and the ordinates correspond to the coefficient $(S)/S_0$. The respective values of this coefficient for silica contents of 10, 12·5, 15, 17·5%, &c., have been taken from Figs. 2 to 7, and their relationship to the lime content has been obtained from the individual curves in Fig. 8 so as to produce a family of curves representing 10 to 30% of silica.

The diagram is valid for about 1600° C. with 0% of manganese in the steel. The samples of slag used in its compilation contained up to 10% of MgO (average 5·8%), up to 5% of Al_2O_3 (average 2·9%), and up to 3% of P_2O_5 (average 1·7%); the samples of steel contained up to 0·050% of P_2O_5 (average 0·017%).

It can be seen from the diagram that with low silica contents the partition coefficient for sulphur increases very considerably as

the lime content is increased, so that desulphurisation is thereby improved. With high silica contents, however, this effect of an increasing lime content is much less marked, and may even be of negligible importance. The summarising diagram shows, further, that the concept of " basicity " as expressed by the ratio CaO/SiO_2 is totally useless for defining the phenomena of desulphurisation; thus, a slag containing 40% of CaO and 25% of silica has the same sulphur partition coefficient (about 1·5) as a slag containing 50% of CaO and 25% of silica, although the ratio of basicity is 2 in the latter case as against 1·6 in the former.

In order to apply the results of Fig. 8 to practical operation, the manganese content of the steel must be taken into account—that is, all the $(S)/S_0$ values in the diagram must be multiplied by the coefficient $(1 + 5{\cdot}0\ Mn)$. For instance, if there were 0·3% of manganese in the metal the $(S)/S_0'$ value for the slag mentioned above

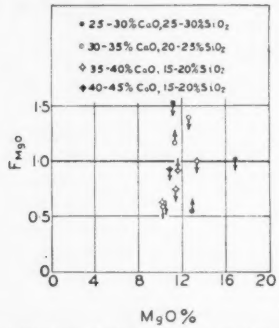

FIG. 9.—Influence of Higher MgO Contents on the Sulphur Distribution.

as containing 50% of CaO and 25% of SiO_2 would be increased from $1{\cdot}50$ to $1{\cdot}50(1 + [0{\cdot}3 \times 5{\cdot}0]) = 3{\cdot}75$, and in order not to have more than 0·020% of sulphur in the metal the sulphur content of the slag must not exceed 0·075%.

(c) *Effect of Higher Magnesia Contents on the Distribution of Sulphur.*—According to Figs. 2 to 7, no influence on the distribution of sulphur is apparent for magnesia contents of up to 10%. To answer the question whether still higher contents of magnesia might exert such an influence a further lengthy series of steel and slag samples was examined in accordance with the procedure described above. From the sulphur contents in the slag " (S) " and in the metal " S," the partition coefficient (S)/S actually existing was calculated, and the partition coefficient corresponding to equilibrium was determined from the lime and silica contents by means of Fig. 8 and from the manganese content of the steel. The quotient obtained on dividing the partition coefficient found in practice by the theoreti-

cal value gives the amount of the deviation, F_{MgO}, if such deviations are referred to the MgO content. The results so obtained from the available samples are presented in Fig. 9, in which the points are differently marked according to the nature of the slag to which they refer. Judging by the position of the points in Fig. 9, desulphurisation would appear to be slightly impaired by higher MgO contents, but in practice the matter is of no importance.

(*d*) *Effect of Higher Alumina Contents on the Distribution of Sulphur.*—Means of determining the effect of higher alumina contents existed in the records of certain heats published in the literature, and for evaluating these data the same methods were used as in the case of magnesia. Fig. 10 shows the results obtained, justifying the qualitative conclusion that the effect of an increased

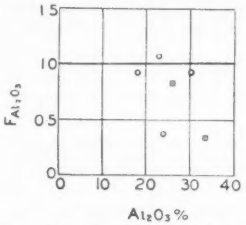

FIG. 10.—Dependence of the Sulphur Distribution on the Alumina Content of the Slag.

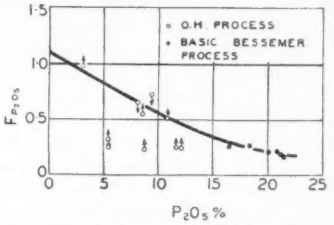

FIG. 11.—Influence of Higher Phosphoric Acid Contents on the Sulphur Distribution.

alumina content in the slag is to reduce the partition coefficient, and, therefore, to hinder desulphurisation.

(*e*) *Effect of Higher Contents of Phosphoric Acid on the Distribution of Sulphur.*—For ascertaining the effect of a higher content of phosphoric acid in the slag, use was again made of the analyses collected by the authors in accordance with the principles explained. As the steel samples all contained less than 0·05% of phosphorus, it was not possible to determine the effect of higher phosphorus contents in the metal. The procedure adopted was the same as that used for determining the effect of magnesia: The actual partition coefficient was calculated from the sulphur contents of the slag and metal, and the value to be expected on theoretical grounds was found from the lime and silica contents of the slag and the manganese content of the metal; the ratio of these two values then serves to measure the deviation of the actual from the theoretical position of the partition coefficient. If the quotients are plotted as $F_{P_2O_5}$ against the respective contents of phosphoric acid, as in Fig. 11, the resulting curve serves to fix, with a good deal of certainty, the dependence of the sulphur distribution on the phosphoric acid content of the slag. The solid points without arrows indicate ratios

obtained from final samples in basic Bessemer heats, and, since these conform perfectly with the trend of curves obtained from basic open-hearth heats, it is clear that the same laws governing the distribution of sulphur between the steel and slag hold good for the basic Bessemer process, exactly as might have been foreseen on physico-chemical grounds. Since the fundamental diagram in Fig. 8 has been compiled with reference to samples of slag containing an average of 1·7% of phosphoric acid, it follows that the curve, in Fig. 11, at 1·7% P_2O_5 must pass through $F_{P_2O_5} = 1$.

In this connection it may further be remarked that the curve determined in Fig. 11 should not follow the same course for all ranges of slags. The slags actually used contained from 35 to 55% of CaO and from 6 to 15% of SiO_2. Closer determination of the curve would have necessitated a considerably greater number of steel and slag samples; however, the range of slags specified here is large enough to give a fair assurance that the conditions usually obtaining in steel manufacture are represented.

The shape of the curve indicates that the effect of the phosphoric acid is to reduce the partition coefficient very appreciably; thus, if the content of phosphoric acid be increased from 10 to 12% the coefficient (S)/S is reduced by half—an effect which corresponds closely with that produced by a 2% increase in the silica in slags containing over 20% SiO_2. In the case of slags poorer in SiO_2, the effect of phosphoric acid is greater than that of silica in impairing the desulphurisation, as is apparent from Fig. 8. The effect of phosphoric acid is explained by the formation of calcium phosphate, whereby the desulphurising action of a corresponding quantity of CaO is nullified.

(*f*) *Effect of Phosphorus in the Metal Bath on the Distribution of Sulphur.*—In an earlier work,[22] the authors have already established the fact, in reference to the distribution of phosphorus between the metal and slag, that the presence of manganese brings about a very large reduction in the phosphorus content, which governs the phosphorus distribution; in other words, the affinity of phosphorus is greater for manganese than for iron. Consequently, it is also to be expected that an increased phosphorus content in the metal bath, by combining with part of the manganese, will reduce the amount of manganese available for desulphurisation. The authors' collection of steel and slag analyses was once again drawn upon for the purpose of resolving this question. Proceeding in the same way as for MgO, Al_2O_3, and P_2O_5, the actual partition coefficient was calculated from the sulphur contents of the slag and steel samples respectively; the theoretical partition coefficient for zero manganese was then read off from Fig. 8 in accordance with the lime and silica content of the slag; the latter was multiplied by (1 + 5·0 Mn) to correspond with the manganese content of the metal, and by $F_{P_2O_5}$ to correspond with the phosphoric acid content of the slag, as shown in Fig. 11. The actual coefficient was divided by the theoretical value found in this

way, giving the points marked in Fig. 12 for the respective phosphorus contents of the metal. The curve could then be drawn to pass between the points, rendering the effect of the phosphorus on the distribution of sulphur clearly apparent. Since the average value of the phosphorus content in all the samples recorded in the original diagram was 0·017%, it follows that at 0·017% of phosphorus the curve must pass through 1·0.

It is manifest, then, that an increase in the phosphorus content of the metal greatly impairs the desulphurising action. The curve in Fig. 12, while requiring to be more accurately determined from more ample experimental material, serves to explain a fact already known to the practical man, namely, that in the course of the melting process the sulphur and phosphorus contents usually change in the same direction, high phosphorus contents occurring simultaneously with high sulphur contents and *vice-versa*.

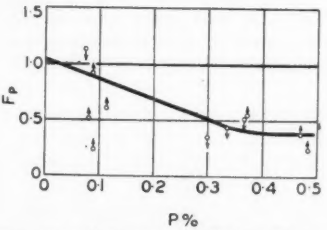

FIG. 12.—Influence of Higher Phosphorus Contents in the Steel on the Sulphur Distribution.

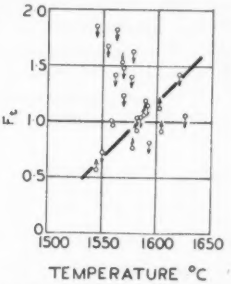

FIG. 13.—Influence of the Temperature on the Sulphur Distribution for slags with 35–45% of CaO.

(*g*) *Effect of Carbon on the Distribution of Sulphur*.—The number of analyses available did not enable the effect of varying carbon content on the sulphur distribution to be determined.

(*h*) *Effect of Temperature on the Distribution of Sulphur*.—To determine the dependence of the sulphur distribution on the temperature, use was made of a number of the steel and slag samples which had already been drawn upon for Figs. 2 to 7. Once again the actual partition coefficient was divided by the theoretical value calculated from the CaO, SiO_2, and manganese contents, and the quotient was plotted in Fig. 13. Neglecting three scattered points with arrows pointing in the wrong directions, the curve for the temperature relationship can be drawn with fair certainty in the temperature range 1550–1625° C. As the temperature rises the partition coefficient for sulphur increases—in other words, a high temperature favours desulphurisation. No effect of the composition of the slag on the temperature relationship could be established from the available slags containing 35–45% of CaO.

C.—Behaviour of the Sulphur in the Acid Open-Hearth Process.

As may be seen from Fig. 8, the partition coefficient for sulphur is greatly reduced by the presence of silica, so that a slag still containing 30% of CaO with 30% of SiO_2 reaches the low value for $(S)/S_0$ of 0·75. The partition coefficients for iron-manganese-silicate slags containing little or no lime should be still lower, as is confirmed by experiments, not yet published, on pure iron-silicate slags. The desulphurising reactions that occur in the acid open-hearth process are, in fact, quite different from those in the basic process.

Changes in the Sulphur Content of the Steel and Slag during the Progress of Melting in the Acid Process.—Up to now no statement has been put on record regarding the behaviour of sulphur in the acid process, and published accounts of heats made by this process include no information as to the sulphur contents of the slags. In Tables I. to VI. such records are given for the first time, being complete analyses of the reactions that occurred in six open-hearth heats. The analyses entered in Tables I. and II. refer to the progress of heats with 18- and 19-ton charges, respectively, and it is note-

Table I.—*Course of Heat* A1 *in the Acid O.H. Furnace* (*without Pig Iron addition*).

Sample No.	Analysis of Steel.					Analysis of Slag.					Ratio $\frac{(S)_{Slag}}{S_{Metal}}$
	C. %	Mn. %	Si. %	P. %	S. %	SiO_2. %	CaO. %	Fe. %	Mn. %	S. %	
1	1·00	0·14	Trace	0·039	0·040	54·5	3·2	18·3	12·2	0·034	0·85
2	0·91	0·08	Trace	0·041	0·038	48·3	5·9	22·2	10·5	0·028	0·68
3	0·74	0·06	Trace	0·043	0·038	54·5	3·9	21·0	8·4	0·028	0·74
4	0·62	0·06	Trace	0·046	0·039	60·1	3·7	16·2	9·0	0·031	0·79
5	0·51	0·06	Trace	0·050	0·042	59·2	4·8	16·0	8·8	0·034	0·81
6	0·41	0·06	Trace	0·052	0·042	60·3	7·7	14·0	8·5	0·029	0·69
7	0·36	0·07	Trace	0·052	0·045	63·0	9·9	9·5	8·5	0·035	0·78

Table II.—*Course of Heat* A2 *in the Acid O.H. Furnace* (*without Pig Iron addition*).

Sample No.	Analysis of Steel.					Analysis of Slag.					Ratio $\frac{(S)_{Slag}}{S_{Metal}}$
	C. %	Mn. %	Si. %	P. %	S. %	SiO_2. %	CaO. %	Fe. %	Mn. %	S. %	
1	0·58	0·10	Trace	0·070	0·054	52·0	6·2	20·1	9·0	0·020	0·37
2	0·57	0·10	Trace	0·080	0·054	51·8	7·0	19·2	9·0	0·020	0·37
3	0·43	0·07	Trace	0·067	0·055	58·0	6·5	16·9	7·0	0·024	0·44
4	0·39	0·07	Trace	0·069	0·056	57·0	7·7	16·0	7·5	0·022	0·39
5	0·33	0·07	0·01	0·072	0·054	58·3	8·9	15·0	7·5	0·020	0·37
6	0·30	0·08	0·03	0·072	0·054	59·8	8·9	14·3	7·3	0·022	0·41
7	0·35	0·66	0·35	0·075	0·050	60·3	8·9	12·7	8·3	0·022	0·44

TABLE III.—*Course of Heat* B1 *in the Acid O.H. Furnace (with normal Pig Iron addition).*

Sample No.	Analysis of Steel.					Analysis of Slag.					Ratio $\frac{(S)_{Slag}}{S_{Metal}}$
	C. %	Mn. %	Si. %	P. %	S. %	SiO_2. %	CaO. %	Fe. %	Mn. %	S. %	
1	0·61	0·17	0·03	0·025	0·025	53·1	0·2	13·0	20·9	0·056	2·24
2	0·50	0·15	0·03	0·025	0·026	51·9	0·3	16·3	18·5	0·021	0·81
3	0·42	0·20	0·04	0·025	0·024	54·7	0·3	13·0	19·6	0·031	1·29
4	0·38	0·17	0·04	0·026	0·025	54·2	0·3	13·8	19·0	0·040	1·60
5	0·26	0·16	0·04	0·026	0·025	55·4	0·2	12·8	19·2	0·033	1·32
6	0·22	0·17	0·03	0·026	0·026	52·3	0·3	15·6	18·7	0·038	1·46
7	0·18	0·16	0·03	0·026	0·026	53·4	0·4	14·6	18·8	0·040	1·54
8	0·16	0·16	0·04	0·029	0·026	54·1	0·5	14·4	18·8	0·058	2·23
9	0·17	0·64	0·45	0·029	0·025	54·6	0·4	12·8	19·9	0·041	1·64
10	0·20	0·65	0·37	0·029	0·024	55·7	0·3	10·7	20·9	0·030	1·25

TABLE IV.—*Course of Heat* B2 *in the Acid O.H. Furnace (with normal Pig Iron addition).*

Sample No.	Analysis of Steel.					Analysis of Slag.					Ratio $\frac{(S)_{Slag}}{S_{Metal}}$
	C. %	Mn. %	Si. %	P. %	S. %	SiO_2. %	CaO. %	Fe. %	Mn. %	S. %	
1	0·98	0·22	0·03	0·022	0·029	45·6	0·50	9·2	28·2	0·029	1·00
2	0·93	0·23	0·04	0·020	0·028	44·6	0·50	9·6	27·3	0·036	1·29
3	0·94	0·23	0·03	0·025	0·028	46·5	0·50	9·5	27·2	0·028	1·00
4	0·91	0·22	0·04	0·021	0·027	45·0	0·50	10·8	26·2	0·046	1·70
5	0·87	0·25	0·03	0·023	0·028	43·8	0·50	13·6	24·7	0·039	1·30
6	0·84	0·24	0·05	0·021	0·028	48·1	0·50	11·4	23·9	0·041	1·46
7	0·71	0·21	0·04	0·020	0·028	47·8	0·50	11·8	22·8	0·039	1·39
8	0·65	0·22	0·07	0·022	0·028	52·9	0·21	10·7	21·7	0·041	1·46
9	0·53	0·28	0·06	0·028	0·029	52·2	0·31	11·0	21·0	0·032	1·14
10	0·47	0·25	0·09	0·024	0·029	53·9	0·36	9·6	21·1	0·041	1·41
11	0·40	0·25	0·12	0·023	0·028	54·7	0·31	10·4	20·6	0·045	1·60
12	0·34	0·25	0·11	0·024	0·028	55·2	0·36	9·6	20·3	0·033	1·18
13	0·34	0·36	0·34	0·025	0·027	56·4	0·31	8·9	20·1	0·035	1·30
14	0·32	0·36	0·28	0·020	0·026	57·8	0·31	8·5	20·4	0·047	1·81

TABLE V.—*Course of Heat* B3 *in the Acid O.H. Furnace (with normal Pig Iron addition).*

Sample No.	Analysis of Steel.					Analysis of Slag.					Ratio $\frac{(S)_{Slag}}{S_{Metal}}$
	C. %	Mn. %	Si. %	P. %	S. %	SiO_2. %	CaO. %	Fe. %	Mn. %	S. %	
1	1·71	0·65	0·45	0·017	0·013	55·8	1·4	12·5	15·9	0·038	2·92
2	1·68	0·58	0·38	0·012	0·012	53·2	1·0	13·4	16·1	0·046	3·83
3	1·68	0·45	0·30	0·014	0·013	51·9	1·2	14·2	16·8	0·034	2·62
4	1·69	0·33	0·19	0·017	0·013	48·8	0·8	17·3	16·4	0·041	3·16
5	1·68	0·24	0·12	0·016	0·012	53·1	0·8	13·6	17·0	0·036	3·00
6	1·61	0·16	0·06	0·016	0·012	54·8	0·7	14·0	16·0	0·033	2·75
7	1·46	0·17	0·07	0·016	0·012	56·9	0·7	13·7	14·7	0·038	3·17
8	1·28	0·21	0·10	0·016	0·011	57·6	0·8	15·1	13·5	0·038	3·46
9	1·21	0·22	0·17	0·017	0·011	56·7	0·7	16·1	12·6	0·041	3·73
10	1·14	0·22	0·21	0·016	0·011	56·8	0·6	17·0	12·3	0·044	4·00
11	1·10	0·22	0·23	0·017	0·011	55·7	0·5	16·5	11·7	0·035	3·18
12	1·07	0·22	0·26	0·017	0·012	55·6	0·6	17·4	11·6	0·036	3·00
13	1·06	0·26	0·26	0·016	0·012	56·3	0·4	17·8	11·3	0·031	2·58
14	1·01	0·29	0·40	0·017	0·012	57·1	0·4	18·2	11·4	0·031	2·58
15	1·01	0·28	0·41	0·018	0·013	56·9	0·3	18·7	11·2	0·044	3·38

TABLE VI.—*Course of Heat* B4 *in the Acid O.H. Furnace (with normal Pig Iron addition).*

Sample No.	Analysis of Steel.					Analysis of Slag.					Ratio $\frac{(S)_{Slag}}{S_{Metal}}$
	C. %.	Mn. %.	Si. %.	P. %.	S. %.	SiO_2. %.	CaO. %.	Fe. %.	Mn. %.	S. %.	
1	1·13	0·42	0·17	0·029	0·020	47·0	0·36	12·6	23·7	0·042	2·10
2	1·09	0·30	0·10	0·029	0·021	47·9	0·41	13·3	22·4	0·043	2·05
3	1·03	0·25	0·04	0·029	0·022	49·9	0·41	11·1	23·2	0·040	1·82
4	0·98	0·28	0·09	0·028	0·021	53·0	0·47	10·4	21·9	0·039	1·86
5	0·73	0·35	0·20	0·029	0·022	53·4	0·47	8·6	20·8	0·038	1·73
6	0·62	0·36	0·22	0·028	0·023	56·3	0·41	8·4	20·5	0·040	1·74
7	0·57	0·63	0·36	0·030	0·022	57·3	0·41	8·2	20·6	0·037	1·68

worthy that in both cases the charges consisted almost entirely of scrap, and, therefore, were worked under unfavourable conditions in regard to the additions. The other heats, recorded in Tables III. to VI., were made with the usual charges of pig iron under favourable conditions, and correspond to 17·5-, 23·1-, 23·3-, and 60·0-ton charges, respectively.

While in this case the sulphur contents in the steel do not differ in magnitude from those in the steel made by the basic process, the sulphur contents in the slag are here much lower than in the basic process, and may be as low as one-tenth of the latter. All the heats show only very small changes in sulphur content during the process, even when—as is particularly true in the case of Table IV.—the composition of the slag undergoes important changes.

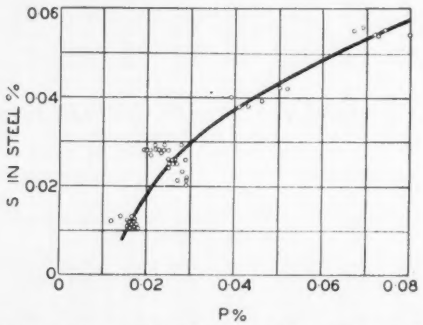

FIG. 14.—Relation between the Sulphur and Phosphorus Contents in the Steel in the Acid Process of Steel Making.

Every attempt to establish the fundamental principle of sulphur distribution from the same point of view as in the basic process proved abortive. The heats yielded no evidence that the partition coefficient (S)/S (entered in the last column of the tables) is depen-

dent on the content of silica, ferrous oxide, or manganous oxide in the slag, or on that of manganese in the metal.

If, however, the sulphur content is plotted against the phosphorus content of the metal, the result is that given in Fig. 14. The sulphur content of the bath is seen to increase with the phosphorus content, and despite the diversity of the origin and of the charging and melting conditions of the respective charges the scattering of the points in the diagram is comparatively small. Not only, however, is the sulphur content of the metal increased as the phosphorus content rises, but at the same time (if less plainly) the sulphur content of the slag decreases as the phosphorus content increases; this is apparent from Fig. 15. In accordance with this interpretation the partition coefficient for sulphur, which in Fig. 16 is correlated with the phosphorus content on the basis of the data contained in Tables I. to VI., falls off as the phosphorus content increases.

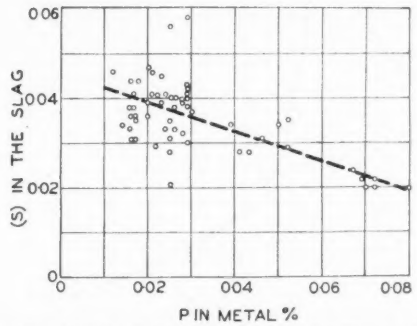

FIG. 15.—Dependence of the Sulphur Content in the Slag on the Phosphorus Content in the Steel in the Acid Open-Hearth Process.

It is a strange fact that while with low phosphorus contents the partition coefficients obtained from Fig. 8 for acid slags are less than 1, the partition coefficients in Fig. 16 rise as high as 4, which would correspond in Fig. 8 to medium basic slags. The inference is that, even if the trend of the curve in Fig. 16 may be interpreted in terms of the effect of phosphorus according to Fig. 12, this trend is not attributable to chemical causes alone. It is rather to be assumed that the charge condition is reflected in the shape of the curve—particularly in Fig. 14—for a bad charge containing much phosphorus will also hold much sulphur, and an exchange of sulphur between the metal and the silicate slag will occur only very slowly. Correspondingly, samples with high manganese contents disclose no improvement in desulphurisation. The relation which emerges from Figs. 14 and 16 is in no way disturbed even by deoxidation with ferro-manganese. In regard to the sulphur distribution in the

acid process, one cannot, therefore, speak of equilibrium conditions in the physico-chemical sense.

These conditions in the acid process would appear to be a consequence of the high viscosity of the acid slag. Independently of this circumstance, the presence of sulphur in the fuel gas always implies the danger of an increased absorption of sulphur, which cannot later be combated, as in the basic process, by removing and replenishing the slag.

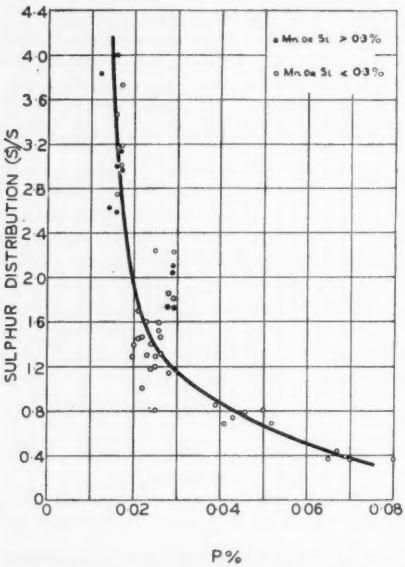

FIG. 16.—Dependence of the Sulphur Distribution in the Acid Process of Steel Making on the Phosphorus Content of the Metal.

SUMMARY.

The distribution of sulphur between the slag and the metal in the basic process was established from operating results. From this a quantitative determination was obtained of the effect of manganese and lime in bringing about a distribution favourable to desulphurisation, and of silica, phosphoric acid, and phosphorus in impairing this action. Qualitatively it appears also that a high content of magnesia and alumina causes a reduction in the partition coefficient. By increasing the temperature desulphurisation is very considerably improved.

In the acid open-hearth process, of which several reports of heats

were taken as examples and interpreted with due regard to the sulphur content of the slags, no clearly discernible equilibrium condition exists in the physico-chemical sense of the term. It appears that the distribution of sulphur between the slag and metal is determined by the quality of the charge, and in this way it becomes possible to explain the clearly established dependence of the sulphur content of the metal and of the partition coefficient on the phosphorus content of the metal.

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CORRESPONDENCE.

Dr.-Ing. HERMANN SCHENCK (Essen) wrote that, while the curves given by the authors in Fig. 8 appeared to represent the conditions for the open-hearth process in a truly simple fashion and with sufficient accuracy for practical purposes, yet he had the impression that for the basic electric furnace particular attention must be paid to the degree of oxidation of the slag. As was known, in the basic electric furnace process very high values for the ratio (S)/S, reaching as much as 50, could be obtained. According to Fig. 8, a typical electric furnace slag with, for instance, 17·5% of SiO_2 and 55% of CaO could produce desulphurisation values, $(S)/S_0$, of only 3, which, on the authors' data, would rise to only 10·5 with 0·5% of manganese in the steel. That demonstrated that in further researches account should be taken of the degree of oxidation of the slag, which could be expressed roughly by its content of iron.

Undoubtedly the degree of oxidation of the slag also played a part in the basic open-hearth furnace; it appeared, however, that this influence was implicitly assumed by the authors, in that they had introduced the coefficient for the influence of the manganese in the steel. The fact that a higher manganese content led to improved desulphurisation was probably to be explained by the simultaneous co-operation of various factors, namely, (1) the formation of manganese sulphide, and (2) the fact that in normal open-hearth practice a higher manganese content was to be regarded as an indication of a lower degree of oxidation.

Dr.-Ing. HANNS WENTRUP (Essen) wrote that in Part C of their paper, in which the authors studied the behaviour of sulphur in the acid open-hearth furnace, they formed the opinion that the partition coefficient of sulphur, (S)/[S], was independent of the silica, ferrous-oxide, and manganous-oxide contents of the slag or the manganese content of the steel. They found merely that some connection existed between the sulphur and phosphorus contents of the steel; this connection, however, was not governed by any physico-chemical law, but was attributable rather to the fact that the lower-grade sulphur-rich additions made to the individual heats examined carried correspondingly higher contents of phosphorus.

The absence of any relation between the manganese and sulphur contents of the steel and slag seemed surprising, because Bardenheuer and Geller [1] had shown that MnO in the slag reacted with FeS to form MnS, and therefore the desulphurising action of FeO–MnO slags increased as their manganese content rose. To be sure, that regularity would be strongly affected in acid slags by the presence of SiO_2, but it was to be assumed that the original tendency, even if

[1] *Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung*, 1934, vol. 16, p. 77.

weakened, would still persist. The researches of Körber and Oelsen [1] on the solubility of sulphur in silicate slags confirmed this assumption.

For this reason, the values reported by the authors were collected together in diagrams drawn from three points of view. In

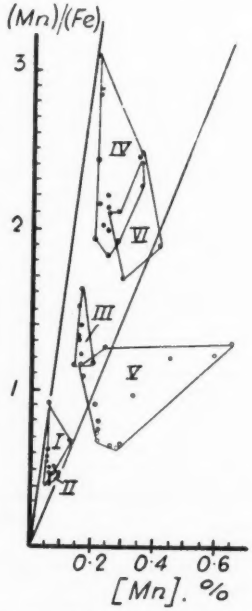

FIG. A.—The Relationship between (Mn)/(Fe) and [Mn].

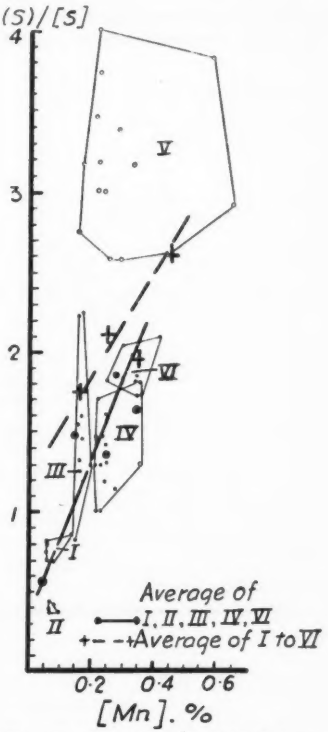

FIG. B.—The Relationship between the Partition Coefficient (S)/[S] and the Manganese Content of the Steel.

Fig. A the manganese content of the metal was plotted against the Mn/Fe ratio in the slag. The values for heats Nos. I., II., III., IV., and VI. (using the Table Nos. to designate the heats) indicated the known equilibrium ratio. Only heat No. V. was not in the sequence;

[1] *Stahl und Eisen*, 1936, vol. 56, pp. 433–444; *see* particularly Figs. 22 and 23.

as was shown by the composition (in Table V.), the working of this heat differed widely from that of the others, for the FeO content of the slag increased continuously, the MnO content decreased, and the carbon content was considerably higher.

In Fig. B the manganese content of the metal was compared with the partition coefficient (S)/[S]. It was unmistakable that the coefficient increased with rising manganese content. This became still more obvious when the values were grouped according to the

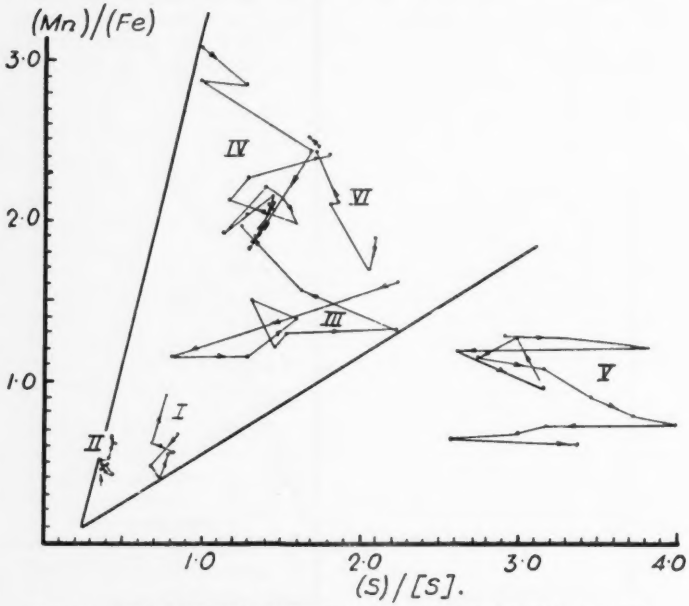

FIG. C.—The Relationship between the Partition Coefficient (S)/[S] and the Ratio (Mn)/(Fe) in the Slag.

manganese content and the average values of the coefficients were found. The final values for heats Nos. II., III., and VI., which were interfered with by the addition of manganese, were omitted. It was interesting that the order of magnitude of the average values agreed well with the laboratory experiments of Körber and Oelsen.

Finally, in Fig. C the Mn/Fe ratio in the slag was compared with the sulphur partition coefficient. Heats Nos. I., II., III., IV., and VI. fell well in line with one another, in the sense that with increasing Mn/Fe ratio the slag dissolved more sulphur. Further, the diagram showed how the generally observed relation persisted also between

the individual heats. As the Mn/Fe value increased towards the end of the heat, so the sulphur coefficient also became larger.

It must be assumed, therefore, that there was a connection between the manganese contents of the heats and the desulphurisation. It would be shown up better, however, when more practically-observed values were available and were considered in closer detail. It was to be hoped, therefore, that the researches of the authors, on which they were to be congratulated, would give rise to still further investigations in this field.

AUTHORS' REPLY.

The AUTHORS wished to thank Dr. Schenck and Dr. Wentrup for their contributions to the discussion. In reply to the former, they would state that complete analyses of the slags and metal baths were available to them only as regards basic open-hearth heats; they were not, therefore, in a position to discuss with Dr. Schenck the question of desulphurisation in reference to slags obtained in the electric furnace.

The further conclusions developed by Dr. Wentrup from the authors' acid open-hearth heats would appear somewhat problematical, seeing that according to these heat V. gave an entirely different result from heats III., IV., and VI., though carried out under the same conditions.

They hoped that Dr. Schenck and Dr. Wentrup would themselves follow up the ideas they had raised by carrying out the appropriate experiments—an undertaking which their connection with one of the largest steel firms in Germany should render immediately feasible to them. The authors might, however, be allowed to observe that in any experiments made with the electric furnace account must be taken of the possible presence of fluorspar in the slag.

A STUDY OF THE ORIGIN OF POROSITY IN THE TIN COATING OF TINPLATE.*

By A. W. HOTHERSALL (Research Department, Woolwich) and J. C. PRYTHERCH (International Tin Research and Development Council).

Summary.

Tinplate sheets of various grades have been examined with a view to correlating the position of pores in the tin coating with visual imperfections or peculiarities of the tinplate. Pores were located by slight rusting in distilled water; their position was marked and the rust removed by a brief cathodic treatment in alkali; the tinplate was then examined microscopically.

In finished tinplate, 30–50% of the pores in the coating were found in scratches produced in the final cleaning and polishing of the tinplate.

Microscopic examination of tinplate carrying less than 2 lb. of tin per basis box (22·4 g. per sq. m.) revealed the presence of periodic bands of scruff (crystals of iron-tin alloy embedded in the coating) running at right angles to the direction of tinning. In tinplate withdrawn from the top of the grease-pot (*i.e.*, without passing through the cleaning or polishing rolls), pores in the tin coating were chiefly located in the scruff bands (41%) and in grease marks (34%).

Scruff bands were not seen in tinplate carrying more than 3 lb. of tin per basis box (33·6 g. per sq. m.) but the largest grease marks of saucer-shape were grouped in periodic bands running at right angles to the direction of tinning; practically all the pores not associated with scratches were located in these bands.

Discontinuities in the tin coating could be seen under the microscope at the site of the pores. Other discontinuities of similar appearance were also seen, a number of which could be made to respond to the hot-water test by lightly etching or stretching the tinplate. These discontinuities have been classified as potential pores. Only one-third to one-fifth of the total number of discontinuities or potential pores responded to the hot-water test.

The alloy layer remaining on tinplate after dissolution of the tin coating in a medium to which the alloy layer is practically inert was found to be highly porous; the porosity was considerably increased by slight stretching of the sheet. Coincidence of discontinuities in the tin coating and in the compound layer appears to be necessary for the existence of pores which respond to the recognised tests. The increase in the porosity of tinplate produced by slight deformation appears to be due to the increased porosity of the alloy layer, which raises the probability of such coincidence.

Introduction.

One of the chief defects in hot-dipped tin coatings on steel (tinplate) is the presence of pores, or discontinuities in the coating, at which

* Received February 5, 1936.

This report is the result of co-operative work by the Research Department, Woolwich, and the International Tin Research and Development Council. The work carried out at Woolwich was undertaken with the aid of funds provided by the Council, the arrangements being made through the British Non-Ferrous Metals Research Association.

steel is exposed. As a preliminary to a study of the causes of porosity in hot-dipped tin coatings on steel an examination has been made of tinplate of various grades, with the object of determining the location of pores in relation to surface peculiarities or imperfections. The results of this examination have enabled the authors to assess the importance of certain types of imperfection in the tinplate as a source of pores in the coating, and indicate lines of work on which a further study of the problem may be profitably pursued.

Methods of Examination.

(1) *Location of Pores.*—The degreased tinplate was first immersed in hot distilled water, as in porosity testing by the hot-water method,[1] for just sufficient time to develop rust spots at the site of pores to a size which could be clearly seen through a small pocket lens. The rust spots were circumscribed with a needle point, and the specimen was treated as the cathode for 10 min. in a cold 0·1% solution of sodium carbonate with a p.d. of 4 V. across the cell (as in degreasing prior to hot-water testing). This treatment loosened the rust, which could then be removed by light swabbing with wet cotton wool. The specimen was then dried and examined under the microscope; the pore sites, located by needle scratches, could be accurately determined.

(2) *Micro-examination of Pore Sites.*—The pore sites and surrounding tinplate were carefully explored under the microscope both at high and at low magnifications. To assist this exploration, it was generally found convenient to divide the area under examination into small squares ($\frac{1}{16}$–$\frac{1}{8}$ in., according to the grade of tinplate) by ruling lines with a fine steel point after the specimen had been treated in hot water for a short period, as described, to develop rust at the pores. The appearance of each square under the microscope, both before and after the removal of rust, was sketched out, and a large-scale map of the peculiarities observed was prepared, a correlation between the microscopic and macroscopic observations thus being made possible. Reproductions of maps of tinplates carrying 3·5 lb., 7 lb., and 1 lb. 8 oz. of tin per basis box are given in Figs. 1, 2, and 3 (Plate XIV.).

Distribution of Porosity.

I.—*Tinplate Carrying about* 1 *lb.* 14 *oz. of Tin per Basis Box* (21 *g. per sq. m.**).

Preliminary examination of this, and somewhat inferior qualities of tinplate, showed that a large proportion of the pores were associated with scratches in the coating, made subsequent to tinning. With the assistance of the International Tin Research and Development Council, a number of sheets of tinplate were

* Here and elsewhere in the paper, this refers to the total surface area.

withdrawn at two stages in the process during normal working at a tinplate works: (1) On emerging from the grease-pot rolls, (2) on emerging from the cleaning machine. Examination of these samples enabled a distinction to be made between defects present on the sheet as it emerges from the tin-pot and those produced subsequently as a result of the cleaning and polishing processes. All the sheets examined were "primes."

The results described below were obtained from the detailed microscopic examination of (1) twelve specimens cut from five sheets of tinplate withdrawn from the nip of the grease-pot rolls, and (2) nine specimens cut from six sheets after passage through the cleaning and polishing rolls.

Pores were found to be chiefly associated with the following peculiarities or imperfections in the coatings: Grease marks, "scruff bands," and transverse ripples; a description of each of these terms is given below, and the results of a micro-examination are described later.

Description of Imperfections with which Pores were Chiefly Associated.

Grease Marks.—Grease marks are defined as saucer-shaped depressions in the tin coating, frequently joined by narrow channels running approximately in the direction of tinning. A portion of a typical grease mark is shown in Fig. 4 (Plate XV.). The saucer-shaped depressions vary in diameter from about 0·001 to 0·02 in., and are sometimes elongated; they appear to be associated with runnels or drops of molten grease carried up by the sheet as it emerges from the top pair of grease-pot rolls.[2] Grease marks have been found on all the samples of tinplate so far examined.

In common with other imperfections described in this paper, grease marks are more clearly visible on sheets taken from the top of the grease-pot rolls without having been subjected to any polishing treatment. Grease marks are more apparent in heavy than in light tin coatings.

Scruff Bands.—Scruff bands are defined as narrow bands in which the tin coating is contaminated by the inclusion of minute particles of scruff or $FeSn_2$, which are visible as microscopic excrescences in the coating. The bands run across the sheet at right angles to the direction of tinning.

Scruff bands have been seen on all samples of tinplate (so far examined) carrying less than about 2 lb. of tin per basis box (22·4 g. per sq. m.); they have not been detected on tinplate carrying more than 3·5 lb. of tin per basis box (39 g. per sq. m.). They are usually discernible on finished plates, but can be seen more readily on sheets withdrawn from the top of the grease-pot prior to cleaning.

Scruff bands are not sharply delineated; they can only with difficulty be detected on very low-grade plates, owing to the greater irregularity of the surface. The appearance of scruff bands is

difficult to reproduce : several bands can be seen between each ripple line in Fig. 5 (*see* also Fig. 3).

Several sheets of tinplate of different manufacture were examined to determine the relative positions of the scruff bands on the two

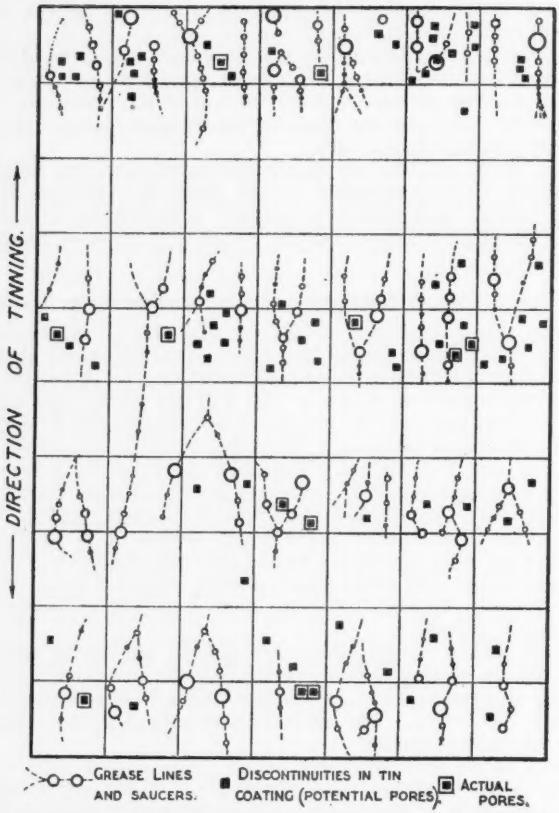

FIG. 1.—Map of Tinplate Surface, showing grease marks, potential and actual pores. Each square represents an area $\frac{1}{6} \times \frac{1}{6}$ in. on the tinplate; 3 lb. 8 oz. of tin per basis box.

sides of a sheet. In none of the sheets was the position of the scruff bands found to be coincident when maps of the two sides of the sheet were matched. The results of measurements of the distance apart of scruff bands on a typical sample are given in Table I.

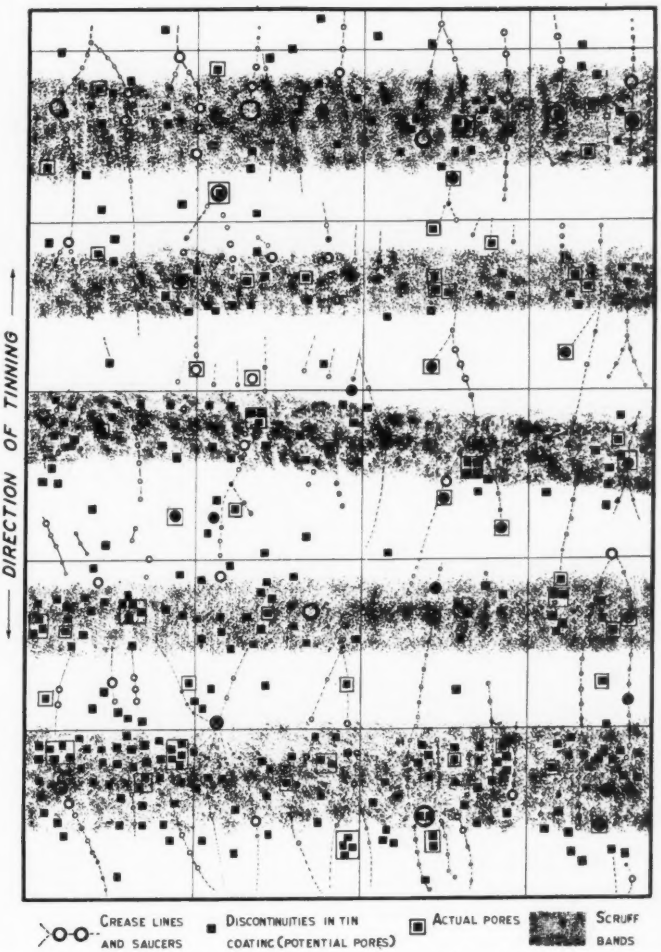

FIG. 3.—Map of Tinplate Surface, showing scruff bands, grease marks, potential and actual pores. Each square represents an area $\frac{1}{8} \times \frac{1}{8}$ in. on the tinplate; 1 lb. 8 oz. of tin per basis box.

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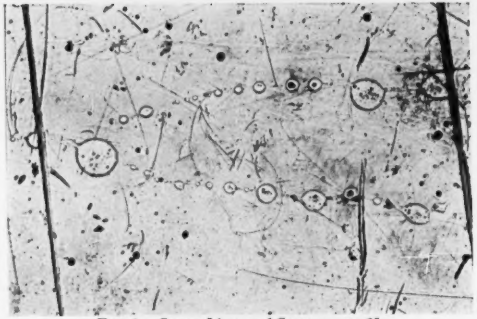

FIG. 4.—Grease Lines and Saucers. × 25.

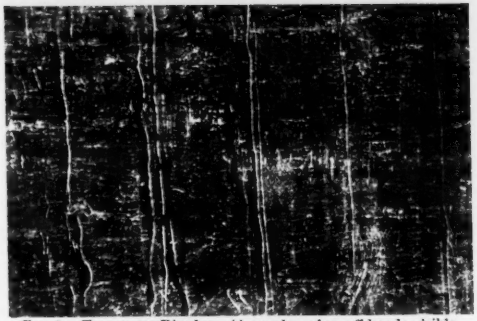

FIG. 5.—Transverse Ripples. (A number of scruff bands visible between the ripple lines.) × 1.

FIG. 6.—Base of Grease Saucer. Etched. × 500.

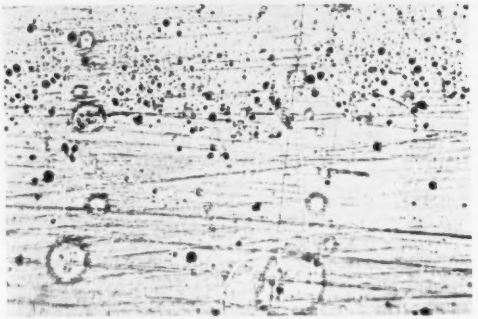

FIG. 7.—Scruff Band, slightly out of focus (dark spots are scruff). × 25.

(Micrographs reduced to four-fifths linear in reproduction.)

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× 25.

(Micrographs reduced to four-fifths linear in reproduction.)

FIG. 8.—Same Field as Fig. 7, but in focus, depicting discontinuities in tin coating (dark spots). × 25.

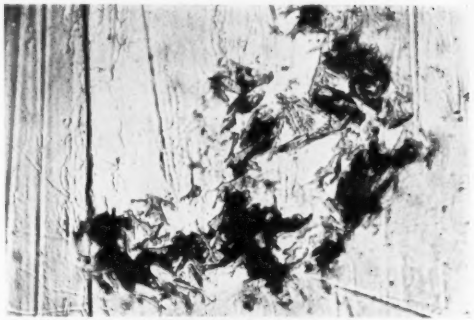

FIG. 9.—One of the Discontinuities shown in Fig. 8. × 1000.

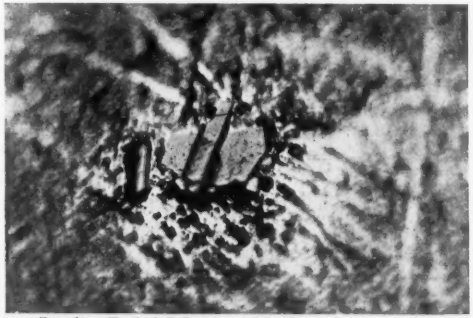

FIG. 10.—Typical $FeSn_2$ Crystal in Scruff Band. × 500.

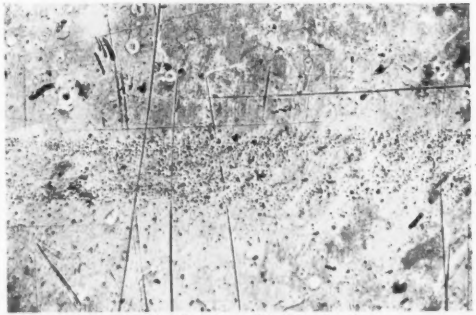

FIG. 11.—Transverse Ripples. × 25.

(Micrographs reduced to four-fifths linear in reproduction.)

PLATE XVI.

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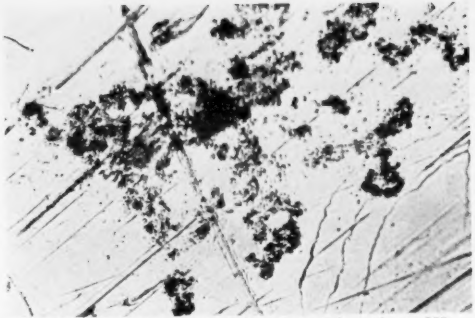

FIG. 12.—Dark Areas in Ripple Line (potential pores). × 500.

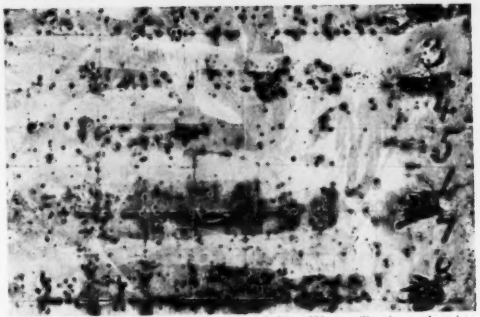

FIG. 13.—Tinplate after Etching and Hot-Water Testing, showing increase of porosity in scruff bands. × 4.

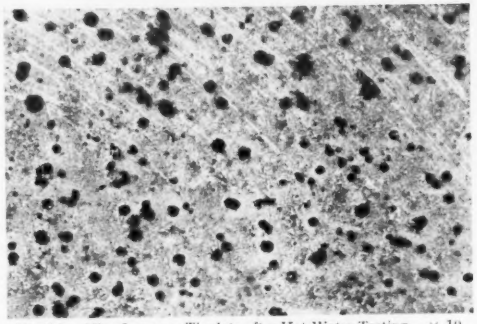

FIG. 14.—Alloy Layer on Tinplate after Hot-Water Testing. × 10.

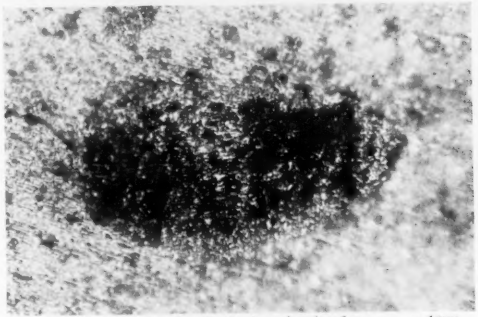

FIG. 15.—Pore Site after Detinning, showing fissures. × 1000.

(Micrographs reduced to four-fifths linear in reproduction.)

[*Holkersell and Pryibercb.*
[*To face p. 209 P.*

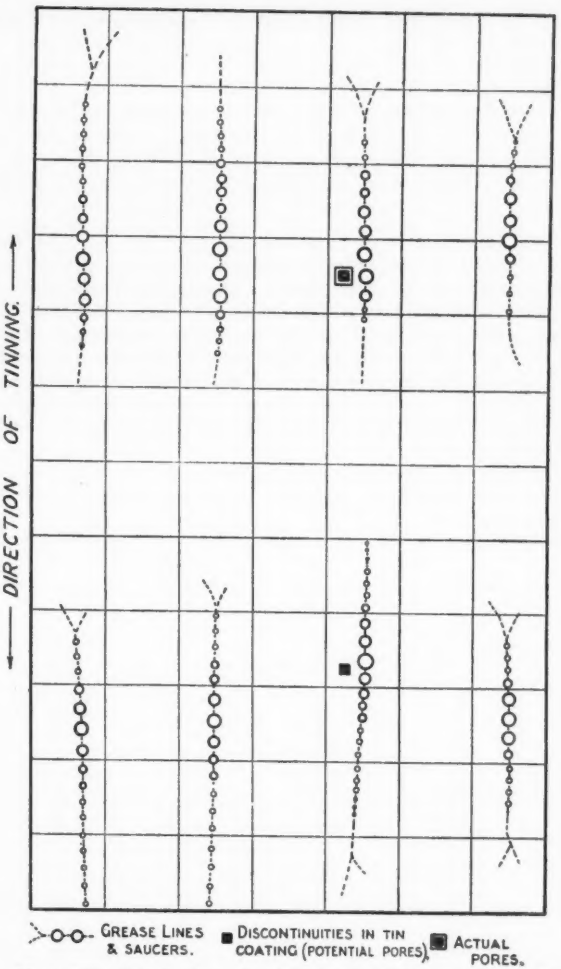

FIG. 2.—Map of Tinplate Surface, showing grease marks, potential and actual pores. Each square represents an area $\frac{1}{6} \times \frac{1}{6}$ in. on the tinplate; 7 lb. of tin per basis box.

Scruff bands were also found on tinplates produced experimentally in a model tin-pot. The average distance apart of the bands on these tinplates was found to be approximately equal to the

TABLE I.—*Spacing of Scruff Bands on Two Sides of a Tinplate.*

Distance from given reference point to centres of consecutive scruff bands. In.																
	Face	0·13	0·33	0·53	0·96	1·27	1·46	1·82	2·12	2·39	2·58	2·78	2·96	3·16	3·37
	Back	0·09	0·38	0·59	0·76	1·05	1·35	1·57	1·90	2·22	2·49	2·62	2·97	3·25	3·47
Distance apart of scruff bands. In.	Face		0·20	0·20	0·43	0·31	0·19	0·36	0·30	0·27	0·19	0·20	0·18	0·20	0·21
	Back		0·29	0·21	0·17	0·29	0·39	0·22	0·33	0·32	0·27	0·13	0·35	0·28	0·22

ratio (roll circumference)/(number of teeth in driving pinion), suggesting that irregular impulses, produced by chatter of the grease-pot rolls, or by slight periodic slip between the roll and the tinplate surfaces, are responsible for scruff bands. Neither in these tinplates, nor in any others, however, were the bands spaced exactly equally; since chatter of the lower grease-pot rolls may be transmitted to the top pair, no simple mathematical relationship or exact spacing of scruff bands would be expected. It is possible that vibrations of the sheet itself in its passage through the rolls may be a contributory factor.

Transverse Ripples.—Transverse ripples are defined as narrow channels (about 0·02 in. wide) in the tin coating, running in a

TABLE II.—*Numerical Classification of Pores. Tinplate* (1 *lb.* 14 *oz.*) *withdrawn from Top of Grease-Pot.*

Specimen No.	Area Examined. Sq. cm.	Number of Pores Associated with—						Total Number of Pores.
		Grease Marks.	Scruff Bands.	Ripple Lines.	Scratches.	Blisters.	Unclassified Defects.	
1	30	90	80	...	18	8	16	212
2	114	201	223	...	30	6	142	602
3	40	24	33	...	10	1	10	78
4	25	75	56	...	18	7	9	165
5	35	39	42	...	9	1	30	121
6	20	42	32	...	8	0	26	108
7	25	54	69	...	13	2	40	178
8	33	66	80	...	10	3	46	205
9	14	35	55	...	20	0	15	125
10	9	75	50	...	7	0	10	142
11	20	46	122	7	3	1	16	195
12	20	21	74	14	9	3	7	128
Total .	385	768	916	21	155	32	367	2259
Average number of pores per sq. dm. . .		199	238	5	40	8	95	Total number of pores per sq. dm. 585
Percentage of total		34	41	1	7	1	16	

direction approximately at right angles to the direction of tinning; they are fairly sharply delineated and easily visible (*see* Fig. 5). The transverse ripples are not usually straight, but are wavy or curved; they may occur singly or in groups of two or more close together. They were noticed on only two of the batches of tinplate examined, on which they were spaced about 0·75 in. apart. As with scruff bands, the position of a transverse ripple on one side of the sheet did not coincide with that on the reverse.

Numerical Distribution of Pores.

The results (for tinplate of quality about 1 lb. 14 oz. of tin per basis box) of counts of pores and their association with the peculiarities described above are given in Tables II. and III. Table II. refers to sheets withdrawn at the top of the grease-pot and Table III. to sheets withdrawn after the usual cleaning and polishing.

Fig. 3 depicts a map of the surface of a tinplate of lower tin yield, but which is also typical of this grade of plate.

The figures indicate that (1) in finished tinplates of this quality (1 lb. 8 oz. of tin per basis box), nearly one-third of the total number of pores are associated with scratches produced in the cleaning and polishing of the sheet after tinning, and (2) the characteristics of tinplate of this quality with which pores are chiefly associated are grease marks and scruff bands. In sheets taken from the top

TABLE III.—*Numerical Classification of Pores. Tinplate (1 lb. 14 oz.) after Cleaning and Polishing.*

Specimen No.	Area Examined. Sq. cm.	Number of Pores Associated with—						Total Number of Pores.
		Grease Marks.	Scruff Bands.	Ripple Lines.	Scratches.	Blisters.	Unclassified Defects.	
13	18	20	47	24	38	4	4	137
14	20	17	30	20	26	6	8	107
15	17	41	33	...	45	3	10	132
16	18	26	44	...	54	3	15	142
17	17	12	54	...	39	5	20	130
18	18	17	47	...	66	3	10	143
19	20	50	43	...	60	1	20	174
20	18	36	50	...	30	1	7	124
21	20	28	102	4	40	1	18	193
Total .	166	247	450	48	398	27	112	1282
Average number of pores per sq. dm. . .		148	271	29	240	16	67	Total number of pores per sq. dm. 771
Percentage of total		19	35	4	31	2	9	

of the grease-pot rolls 34% of the total porosity was associated with grease marks and 41% with scruff bands.

In view of these results, a more detailed microscopic examination of scruff bands, grease marks, and ripple lines was made.

II.—*Tinplate Carrying 3·5–4 lb. of Tin per Basis Box.*

Scruff bands were not found on tinplate of this quality, but the larger grease saucers were, as with tinplate of lower quality, grouped in bands running approximately at right angles to the direction of tinning. Although very few pores were found in the grease marks, almost all the pores which were not associated with scratches were found in the bands of grease saucers. This is illustrated in Fig. 1, which depicts a map typical of the surface of tinplate carrying 3 lb. 8 oz. of tin per basis box.

The examination of tinplate carrying heavier coatings of tin yielded similar results, but with increase in the thickness of tin the bands of grease saucers became more widely spaced. A map of the surface of tinplate carrying 7 lb. of tin per basis box is shown in Fig. 2.

An analysis of the location of pores in commercial tinplate, quality 3·5–4 lb. of tin per basis box, is given in Table IV. Approximately one-half of the pores developed in the hot-water test were

TABLE IV.—*Numerical Classification of Pores. (Tinplate 3·5–4 lb. of Tin per Basis Box.)*

Specimen No.	Area Examined. Sq. cm.	Number of Pores Associated with—				Total Number of Pores.
		Discontinuities Located in Bands of Grease Marks.	Scratches.	Grease Marks.	Unclassified Defects.	
22	24	7	10	0	2	19
23	24	16	14	0	0	30
24	24	10	8	0	1	19
25	50	12	26	1	0	39
26	22	9	14	0	0	23
27	17	3	13	0	0	16
28	17	4	10	0	0	14
29	15	3	10	0	4	17
30	35	10	5	0	0	15
31	19	28	2	0	6	36
Total .	247	102	112	1	13	228
Average number of pores per sq. dm.		41·3	45·4	0·4	5·3	Total number of pores per sq. dm. 92·4
Percentage of total		44·7	49·2	0·4	5·7	

associated with scratches in the coating, and one-half with discontinuities occurring in the bands of grease marks.

Micro-examination of Pore Sites.

I.—*Tinplate carrying* 1 *lb.* 14 *oz. of Tin per Basis Box.*

Grease Marks.—Pores were found chiefly in the saucer-shaped depressions, but some were located in the connecting channels.

With suitable adjustment of the lighting and focus of the microscope, the bases of a number of the grease marks examined showed a rough appearance. After etching lightly with ferric chloride solution, these areas appeared crystalline and similar to the alloy layer after removal of the tin coating, indicating that the tin coating was very thin, and possibly locally absent, at the bases of these grease saucers (*see* Fig. 6). Hoare and Chalmers [4] found that the depth of the grease marks, measured by an optical method, was sufficient to penetrate to the compound layer in a fair percentage of the grease marks they examined.

Examination of the grease saucers before and after removal of the rust spots formed in hot-water testing showed the sites of the pores to be dark areas which appeared to be depressions or discontinuities in the coating. At high magnification crystals of $FeSn_2$ were seen in and around the dark areas (as in Fig. 9 (Plate XVI.); *see* also Fig. 6, which depicts a number of isolated $FeSn_2$ crystals in the base of the grease saucer).

Scruff Bands.—As the microscope is lowered towards a scruff band, dark spots representing elevations in the tin coating due to the inclusion of scruff ($FeSn_2$ crystals) are first brought into focus (*see* Fig. 7). Under a high magnification, the foreign matter was found to consist of large crystals of $FeSn_2$, as indicated in Fig. 10. The tin surface, with scratches and edges of grease saucers, next comes into focus, and the scruff spots disappear. Other dark areas, the position of which is unrelated to that of the scruff spots, are afterwards observed (*see* Fig. 8, showing the same area as Fig. 7). Fig. 9 shows the appearance of one of these areas at high magnification. By careful adjustment of the focus of the microscope, they appeared to be depressions in the tin coating surrounded by relatively large crystals of $FeSn_2$. Pore sites were found to be located at the dark areas, and many of those which did not develop rust spots in the hot-water test revealed slight rust stains under the microscope.

It was frequently observed that the size of the grease saucers varied in a periodic manner in the direction of tinning, and that the largest saucers occurred in or near the scruff bands (*see* Fig. 3). Thus if any one grease line was traced towards the list edge of the sheet, the saucers became smaller as the clean tin surface adjacent to a scruff band was approached. In the area of relatively clean tin between scruff bands, few grease saucers were generally found,

and those present were usually very small. In the next scruff band, large saucers were again found.

A comparison of sheets of different tin yields disclosed that with decreasing thickness of tin, the area of clean tin surface between the scruff bands decreased, and a mottled pattern typical of the appearance of the alloy layer after removal of tin in sodium plumbite solution became visible in the scruff bands. This observation suggests that the tin coating is locally thinner in the area of the scruff bands, since the appearance of a mottled pattern in tinplate has been found to be associated with thin tin coatings.[3]

The presence and direction of the scruff bands appeared to be unaffected by the direction in which the steel had been rolled. Thus the appearance of scruff bands was similar on sheets which had been rolled at right angles to the direction of tinning (determined by bend tests) and on sheets which had been rolled and tinned in the same direction. The bands, therefore, are not associated with any periodic variation in the gauge of the sheet.

Transverse Ripples.—Hoare and Chalmers[4] found transverse ripples to be channels in the tin coating, and this finding was confirmed in the present work by microscopic examination. On immersing a specimen showing ripple lines in dilute *aqua regia*, tin was seen to be completely stripped from the area occupied by the ripple line before any other area, thus indicating local thinness of the tin coating.

Micro-examination revealed a series of small dark depressions or discontinuities in the tin coating crowded together in the ripple lines (*see* Figs. 11 and 12, Plates XVI. and XVII.). Although few of these depressions developed rust spots in the hot-water test, many of them showed slight rust stains under the microscope.

II.—*Tinplate carrying* 3·5–4 *lb. of Tin per Basis Box.*

The special differences noted between this and the lower grades of tinplate examined were (*a*) much lower porosity and greater freedom from imperfections, (*b*) the absence of scruff bands, and (*c*) the very small number of pores found in grease marks.

This grade of sheet otherwise showed similarities to the lower grade in that almost all the pores other than those due to scratches were located in the bands of grease marks running across the sheet at right angles to the direction of tinning (*see* Figs. 1 and 2).

Potential and Actual Pores.

Numerical Relationship.—Many of the discontinuities seen under the microscope in scruff bands, grease marks, and ripple lines were probably the sites of minute pores, since they showed slight rust stains under the microscope after the hot-water test. As they would not be registered as pores by tests ordinarily employed, it is convenient to classify them as potential pores. By actual pores

are meant those which developed rust spots in the hot-water test, or blue spots in the ferroxyl test, visible to the unaided eye.

The relationship between the total number of discontinuities in the tin coating seen under the microscope (potential pores) and the number which developed rust spots in the hot-water test (actual pores) is set forth, for different grades of tinplate, in Table V.

TABLE V.—*Proportion of Actual to Potential Pores in Tinplate.*

Grade of Tinplate.		Area Examined. Sq. cm.	Potential Pores.	Actual Pores.	Actual Pores / Potential Pores %.
Lb. of Tin per Basis Box.	G. of Tin per sq. m.				
10·5	118	128	31	10	33
7	78	64	2	1	...
6	67	24	5	1	20
3·25–4	36–45	429	739	205	28
1·5	17	5	350	60	17

Tests were made to determine the degree to which these potential pores would respond to the hot-water test after subjecting the tinplate to treatments such as light etching, deformation, polishing, &c.

The Effect of Etching, Deformation, &c., on Porosity.—A second application of the hot-water test with intermediate removal of rust in the manner previously described did not appear to increase the number of pores to a marked degree (*see* Table VI.). The effect of various treatments in converting potential into actual pores was therefore examined, using the following method: The total number of discontinuities in the tin coating of a specimen was counted under the microscope; the specimen was then degreased and immersed in hot water for 45 min., when it was again examined under the microscope to determine the number of discontinuities at which rust had formed. The rust was then removed and the specimen subjected to the treatment under test. The hot-water test was then repeated and a count taken of the additional discontinuities which had responded to the test. Rust spots on scratches or on areas not originally registered as discontinuities were neglected.

The results, given in Table VI., show that light etching and stretching produced a marked increase in the number of discontinuities which responded to the hot-water test and confirm the suggestion that these areas represent potential pores. The etching treatment used involved only a slight attack on the tin coating (equivalent to a loss of 1·7 g. of tin per sq. m. (2·4 oz. per basis box) in 30 sec., or 10% of the thinnest coating tested); the attack on the alloy layer amounted to approximately one-seventh of that on the tin coating. The effect of a similar etching treatment in increasing

TABLE VI.—*The Effect of Etching and Stretching on the Conversion of Potential to Actual Pores.*

Grade of Tinplate.		Area Examined. Sq. cm.	Potential Pores.	Treatment Applied.	Actual Pores (Hot-Water Test).	
Lb. of Tin per Basis Box.	G. of Tin per sq. m.				Before Treatment.	After Treatment.
3·5	39·3	60	42	Repeat of hot-water test.	23	25
3·5	39·3	28	105	3% extension on 7 cm. length.	18	55
9	101	6	8	Etching in dil. *aqua regia* for 30 sec.	1	8
3·5	39·3	48	88		23	41
3·5	39·3	20	104		20	35
3·5	39·3	52	81		17	58
1·5	16·8	5	350		60	157
1·5	16·8	5	350	Etching in dil. *aqua regia* for 60 sec.	60	225

the response of potential pores in scruff bands to the hot-water test is shown in Fig. 13.

Other tests revealed that both light polishing (for example, by hand with dry cotton wool) and cathodic treatment in alkali at a high current density increased the response of potential pores to the hot-water test. The latter result confirms the undesirability of cleaning tinplate cathodically in alkali at a high current density prior to hot-water testing.[1]

Porosity of the Alloy Layer on Tinplate.—Tests of the porosity of the alloy layer on tinplate were made to determine the probability of discontinuities in the tin coating coinciding with those on the alloy layer to give pores or exposures of the steel base.

The tin coating on a specimen of tinplate (1 lb. 14 oz. quality) was removed by immersion in boiling sodium plumbite solution for 2–3 min. (the validity of this and another method, referred to below, for removing tin without attack of the alloy layer has been examined and is reported separately [5]). The specimen was then immersed in hot distilled water for 15 min., after which a large number of minute rust spots were visible. Examination under a low-power microscope showed that the spots were fairly evenly dispersed. The specimen was ruled into squares 1·6 × 1·6 mm. and the pores were counted. The results are given in Table VII.

TABLE VII.—*Porosity of the Alloy Layer on Tinplate.*

Number of Squares Examined. (1·6 × 1·6 mm.)	Total Number of Pores.	Number of Pores per Square.			Equivalent Average Porosity. (Number of Pores per sq. dm.)
		Max.	Min.	Average.	
90	700	16	1	8	30,000

The largest discontinuity in tin coatings measured under the microscope in the course of this work was about 0·05 mm. in dia. (a figure which agrees with a measurement recorded by Hoare and Chalmers [4]). It would be possible to crowd 1000 such discontinuities into each of the small squares examined. But the alloy layer was only found to contain an average of eight pores per square. Therefore it would appear that a discontinuity of the type examined in the tin coating will only constitute a pore when it coincides with a pore in the alloy layer. This result affords an explanation of the low proportion of actual to potential pores (*see* Table V.).

Results confirmatory of the high porosity of the alloy layer were obtained with larger specimens detinned either in sodium plumbite solution or by an alternative method of anodic dissolution at controlled potential in sodium hydroxide solution.[5] Tests, described in another paper, showed that with suitable control of the potential, no attack of the alloy layer took place. Similar results were obtained using the ferroxyl test in place of the hot-water test.

A magnified view showing well-defined rust spots on a typical area of the alloy layer on detinned tinplate after the hot-water test is given in Fig. 14.

No attempt has been made to determine the presence of minute pores, not clearly defined by rust spots (after the hot-water test) or by blue spots (after the ferroxyl test), and the possibility is not discounted of the alloy layer being considerably more porous on a minute scale than has been indicated.

Effect of Stretching on the Porosity of the Alloy Layer.—Two samples of tinplate (1 lb. 12 oz. tin per basis box), one in the shape of a flat tensile test-piece, were cut from adjacent positions on a sheet and were then detinned in sodium plumbite solution; the tensile test specimen was stretched in a testing machine to give an extension of 3%. The porosity of both specimens was then developed by the hot-water test, and the rust spots were counted under the microscope. On an area of 6·5 sq. mm., the detinned plate showed 24 pores (37,000 per sq. dm.) and the stretched, detinned plate 150 pores (200,000 per sq. dm.). This result suggests that the increase, produced by slight deformation, in the percentage of visible discontinuities in tin coatings which respond to the hot-water test (potential pores) is due to the effect of deformation on the porosity of the alloy layer.

Conclusions.

It is suggested that the periodic bands of scruff in which the majority of pores (other than those due to cleaning and polishing) were found may be caused by the uneven movement with respect to the tinplate surface of the grease-pot rolls, caused by chatter or slip, possibly associated with vibration of the sheet, as it passes through the rolls. By continued contact with molten tin, these

rolls acquire a loosely adherent coating of iron-tin alloy crystals, some of which would tend to be transferred to the tinned sheet by variations in pressure or uneven movement of the rolls, thus forming periodic scruff bands.

The results suggest that the formation of visible discontinuities in the tin film takes place at the grease-pot end of the tinning machine, since (*a*) these discontinuities are almost entirely located in the scruff bands, and (*b*) only a proportion of the visible discontinuities constitute actual pores, indicating that the chief cause of porosity in the alloy layer is not associated with the chief cause of discontinuities in the tin coating.

The concentration in the scruff bands of pores in the tin coating may be due to one or more of the following causes : (1) Periodic thinning of the molten tin coating by irregular movement of the sheet with respect to the rolls, due to the causes mentioned above, may rupture the film of tin bridging crevices which are not filled with tin or covering areas which are not wetted with tin. This suggestion would imply the presence of such areas over the whole surface of the sheet. It should be noted in this connection that in the microscopic examination of pore sites after detinning in sodium plumbite solution, all of fourteen pore sites examined exhibited gaps or fissures similar to those visible in Fig. 15 (*see* also Fig. 6). (2) Local exposure of the alloy layer, due to deficiency of tin (as, for example, in grease marks). The alloy layer has been shown to be highly porous. (3) The presence of crystals of hard iron-tin alloy (scruff) in the soft tin coating may be a potential source of porosity (similar suggestions have been put forward previously [2]). Many examples of iron-tin alloy crystals of a width greater than ten times the thickness of the tin coating have been seen (Fig. 10, for instance). Handling or cleaning of the sheet would be liable to loosen or dislodge such crystals, leaving gaps in the coating.

The authors wish to express their indebtedness to Mr. J. Taffs, F.R.M.S., for his assistance in providing the photomicrographs.

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DISCUSSION.

Mr. D. J. MACNAUGHTAN (London) said that one point to which he would like to refer was the question which had often been asked, namely, why so much work was being carried out on the porosity of the tin coating. It was said that even if the pores were got rid of in the tinplate as produced in the works, others were bound to be produced as soon as one began fabricating the tinplate. The answer was that if it were possible to produce, without any undue increase in expense, a pore-free tinplate, there would be an undoubted increase in the use of tinplate in a number of directions. Further, it was not necessary to be entirely pessimistic as to the inevitability of the production of pores or breaks during fabrication. That was a subject for further research. It might not be possible to produce pore-free tinplate straight from the tinplate works for some time to come, and it might be difficult to get rid altogether of pores during fabrication, but any reduction in the number of pores from these causes had a considerable bearing on the use of tinplate. Thus, in the case of the can in which corrosion occurred owing to the nature of its contents, the amount of corrosive attack which determined the storage life prior to consumption would be largely dependent upon the number of active centres of corrosion, and these would be related to the number of pores. Any important reduction in the number of pores, even in existing circumstances, was therefore of real importance.

Actually in works he found many people attempting to get over the trouble, even including those who said that there was no hope of doing so. He had witnessed the results of many experiments in the United States and elsewhere. Possibly the most important contribution had come from the Continent recently, where it had been definitely shown, as a result of work carried out, that the pores were *not* due to hydrogen occluded in the steel and liberated during the tinning process. No important improvement had been secured, however, by any modifications so far proposed or tried out, and it had always seemed to him that, in view of the complexity of the problem, it was becoming increasingly important to know more about the nature of the defect itself.

This was possible as there was a reliable test for showing up the presence of pores, namely, the hot water test, and a suitable metallographic technique had been developed for studying their essential characteristics. Earlier work with these methods showed the presence of pores in a very definite manner, and the present research showed how they were distributed, and brought out the remarkable fact that instead of being scattered indiscriminately all over the surface they were largely concentrated in narrow bands across the sheet. That was of extraordinary interest and importance. In the case of the 7-lb. coating, the bands were about $\frac{3}{4}$ in. in width,

while in the case of the 3½-lb. coating they were about ⅛ in. wide. The area between those bands was practically free from pores. In the case of ordinary tinplate (less than 2 lb. of tin per basis box) there were present bands of the order of $\frac{1}{12}$ in. in width, and intervening areas in which the porosity was only one-quarter of the average porosity of the tinplate. That was a definite indication that there was no need for the pessimistic view that "the pore we have always with us," and justified hopes that there was a chance of securing a substantial reduction in the porosity of tinplates.

The authors had not only shown that in tinplates as at present produced a considerable proportion of the area of the sheets was relatively free from pores, but had made certain suggestions as to the cause. The evidence appeared to indicate that in the porous areas the coating was definitely thinner than elsewhere. An important aspect of the problem of securing improvement would be to know the manner in which this thinning took place. At present there was a suggestion from the authors that it might be related to variations in pressure on the sheet as it passed through the rolls in the palm oil. Whether it was actually due to that or not remained to be seen.

With regard to the large number of discontinuities produced by scratching during the cleaning operation—a surprisingly large number—he did not think that that would be such a difficult problem to solve; it was obviously a matter of studying the cleaning operation with a view to its suitable modification.

Mr. W. E. Hoare (London) said he had read the paper with a great deal of interest, and had found it very stimulating, as he had been working on similar lines for the last three years.

It seemed to him that the effective conclusion of the paper was that the authors had been able to establish a banded structure at right angles to the direction of tinning, and that this existed on all grades of tinplate which had been examined. They had further shown that this banded structure was associated with the distribution of porosity. In their tentative suggestion as to how that banded structure occurred, they had divided it into three separate phenomena, calling the first scruff bands, the second ripple lines, and the third grease marks, the latter being found in the higher-grade tinplates. The actual physical difference between those three phenomena did not appear to be too clear, and personally he thought that that might be due to the fact that there was not really any intrinsic difference at all. He would like to join issue with the authors on this point, and to suggest that the banded structure was really a single phenomenon and had a single first cause, although it might have a number of secondary indirect causes.

In that connection, it seemed to him that the authors only noticed the scruff band effect on the lower grades of tinplate which they examined, in other words where *exposure* of compound would

be likely to occur. They also suggested that the evidence of some of their experiments indicated that the tin coating was locally thinner in the area of scruff bands. It seemed to him that such thinness would be very much more significant than any deposition of scruff by chatter of the grease-pot rolls, which frankly he did not think occurred. When one considered a normal curve of porosity against tin yield, one would find that the variations were tremendous, two or three ounces of tin yield making a tremendous difference to the porosity, in particular round about the tin yield of the plates in which the authors found scruff bands.

The ripple lines which the authors mentioned were first seen, he believed, by Dr. Chalmers and himself, and they found them to be not channels in the tin coating, as the authors had suggested, but actually that the ripple marks at right angles to the direction of tinning were parallel ridges and valleys in the tin coating, having an undulating or wave-like contour in the direction of tinning. He had a specimen with him which had been tinned without any grease-pot rolls at all, and it seemed to him to exhibit just that structure which the authors had called scruff bands. He would like to suggest that any circumstances which would cause ripples to be set up in the nip at or above the top pair of grease-pot rolls would cause as its primary direct effect the formation of a structure consisting of linear variations of tin yield at right angles to the direction of tinning. When a sheet was tinned in the ordinary way, conditions for free vibration of the sheet were best at the front and back edges. When the sheet came up from the nip it had a certain amount of freedom before being gripped by the manipulators, and would have a certain freedom again when the back end left the top pair of rolls in the grease-pot; therefore, if the tentative explanation which he put forward was true, one would tend to find ripple conditions and scruff bands accentuated towards the back and front edges of the sheet. On some sheets which he had examined such accentuation did occur.

Ripple marks were found on a large number of tinplates, numbers of specimens showing them very definitely indeed. In that connection he would like to mention that, although the authors had found no coincidence of scruff bands or ripple marks on the back and front sides of the sheet, when one had a definite group of ripples which stood out from the rest of the undulating system one did get coincidence of groups of ripples, though there was no essential coincidence of each individual hill and valley in the tin coating. Were either explanation the true one, one would not expect individual coincidence.

He entirely agreed with the authors' remark that " the increase, produced by slight deformation, in the percentage of visible discontinuities in tin coatings which respond to the hot-water test (potential pores) is due to the effect of deformation on the porosity of the alloy layer," but he did not altogether agree with the way in

which they had arrived at that conclusion. He would have more to say about that at a later date, but it was pleasant to find that the ideas put forward two years ago with regard to potential pores had been so well confirmed by the authors.

He was glad to find that the authors had drawn attention to the porosity produced by the cleaning operations. It was very annoying to find that good plate having a good porosity figure would acquire a largely increased porosity by cleaning. A good deal of attention had recently been directed to this subject in Germany. The present authors had given a figure of 30 to 50% increase of porosity due to cleaning, and he thought that that should be qualified, because with tinplates carrying the higher tin yields he did not think that anywhere near 30 to 50% of the pores were produced by cleaning. If they were talking about $1\frac{3}{4}$-lb. coating they would be about right in their estimate, but above $3\frac{1}{2}$-lb. he thought that that figure was too high. He had done a few experiments himself on cleaning, and, although he had not gone far as yet, one result did seem to emerge, namely, that on commercially cleaned tinplates the chief porosity produced by cleaning was not so much a general abrasion of the tin coating as a series of deep, localised scratches, which seemed obviously to be caused by the intrusion of dirt and grit in the cleaning operation.

In conclusion, he would like to say how important he felt this work to be. The authors had succeeded in producing evidence of an orientation covering a very high percentage of the existing porosity. That such research work would in time lead to the substantial elimination of porosity, he felt no doubt.

AUTHORS' REPLY.

Mr. HOTHERSALL, in reply, said the authors were very glad that Mr. Macnaughtan had referred to the importance of porosity. That question had recently been raised in the discussion of a paper in Germany, and Mr. Macnaughtan had provided a very effective answer to it.

They were also glad to receive the detailed comments by Mr. Hoare, whose well-known work on similar lines made his discussion particularly valuable and informative. The authors would look forward with great interest to the publication of the work to which Mr. Hoare had referred. They found it difficult to reconcile Mr. Hoare's suggestion that scruff bands were not, in fact, "scruff bands" at all, but only local exposures of compound, with their detailed results of examination of commercial tinplates, recorded and illustrated in the paper. They had drawn attention to the fact that the tin coating appeared thinner in the area of the scruff bands, and their observation of the relationship between the porosity

and the weight of coating agreed with that of Mr. Hoare and other workers. This established relationship did not, however, provide an explanation of the cause of the pores, which appeared to the authors to be bound up, in part, with the cause of the scruff bands; in their tentative conclusions, they had attempted to link cause and effect together.

Mr. Hoare was not correct in suggesting that the authors regarded scruff bands, grease marks, and ripple lines as separate and distinct phenomena; they were quite prepared to find that scruff bands and grease marks had a common origin. They had not laid any stress on the phenomenon which they had called ripple lines, because they had seen only a very few examples of tinplates with these markings; scruff bands, on the other hand, had been seen on all the samples of coke tinplates examined.

Reference to Tables III. and IV. would show the percentage of pores found on scratches for two different grades of tinplate of stated tin yield. The authors would not be surprised to find that heavier tin coatings than those examined by them were less liable to damage in cleaning. Mr. Hoare's remarks on this point might, however, be taken to suggest that the authors' result for tinplate carrying 3·5–4 lb. of tin per basis box (*viz.*, 49·2% of the pores associated with scratches) was not representative of this quality. The authors would prefer not to comment on such a criticism in the absence of any figures to support it.

METHODS OF DETINNING TINPLATE FOR EXAMINATION OF THE THICKNESS AND CONTINUITY OF THE ALLOY LAYER.[1]

By A. W. HOTHERSALL and W. N. BRADSHAW (Woolwich).

Summary.

The sodium plumbite method and a new electrolytic method of detinning tinplate have been examined to determine the conditions of minimum attack on the alloy layer. The thickness and porosity of alloy layers on commercial tinplates were examined by the methods developed.

Detinning by the sodium plumbite method involves immersion in the boiling solution for a period of 3–5 min. With an unsuitable composition of solution the alloy layer was markedly attacked, or removal of the tin was slow; with the optimum composition of solution, about 3% of the alloyed tin present on an average grade of tinplate was dissolved per min. The usual time for which the alloy is exposed to attack by the solution is 2–3 min. A recommended procedure is given.

The electrolytic method consists in anodic treatment in 5% sodium hydroxide solution at 30° C.; the potential difference across the cell is controlled and should not exceed 1·0 V. Detinning of an average quality tinplate takes 10–20 min. The attack on the alloy layer in 5 min. amounted to 1·4% of the alloyed tin present on an average grade of tinplate.

In agreement with previously published results, an average of 3·3 oz. of alloyed tin per basis box (2·3 g. per sq. m.) was found on tinplate carrying 2 lb. or less of tin per basis box (22·4 g. per sq. m.). Larger amounts of alloyed tin were found on plates having tin yields in excess of 3 lb. per basis box (33·6 g. per sq. m.), the maximum figure obtained for commercial tinplate being 1 lb. 1·2 oz. of alloyed tin per basis box (12 g. per sq. m.). The heavier alloy layers did not show the mottled pattern typical of the average grade of alloy layer.

The alloy layer of average quality tinplate was found to be highly porous (30,000–70,000 pores per sq. dm.), using both the hot-water and ferroxyl tests. The heavier alloy layers were less porous.

Determinations of the tin yield of heavily coated tinplates by Clarke's method of stripping in hydrochloric acid containing antimony are liable to a slight error when the amount of alloyed tin exceeds the average, because of the altered correction factor required for dissolution of the alloy layer; in an extreme case, this error may amount to 5–6% of the total tin yield. No modification of the correction factor is involved for tinplate carrying less than about 3 lb. of tin per basis box.

Introduction.

Although the properties and thickness of the alloy layer on tinplate are usually considered to be of minor importance in comparison with

[1] Received February 5, 1936.

By arrangement with the British Non-Ferrous Metals Research Association the work described in this paper was carried out at the Research Department, Woolwich, with the aid of funds provided by the International Tin Research and Development Council.

the thickness and continuity of the tin coating, they may be of great significance, not only in affecting the behaviour of tinplate during fabrication and service, but also in giving information on the causes of porosity in the tin coating.

To enable the continuity, structure, and behaviour on deformation of the alloy layer to be examined, and its thickness to be determined, it is necessary to remove the tin coating without attacking the alloy or any exposed steel. A method used for this purpose by Kohman and Sanborn [1] consisted in immersing the tinplate in a boiling solution of sodium plumbite, which rapidly dissolved the tin coating with the precipitation of lead in a finely divided form. A dilute solution of *aqua regia* has also been used, but this solution is known to attack the alloy layer. An examination of these methods and also of an electrolytic method, devised by the authors, has been made, to determine the conditions which result in the minimum attack of the alloy layer; using these conditions, the thickness, appearance, and continuity of the alloy layer on samples of tinplate of various grades have been examined.

Detinning in Sodium Plumbite Solution.

Sodium plumbite solution may be readily prepared by the addition of a solution of lead acetate to one of sodium hydroxide.

Tests of solutions of various compositions were made by immersing samples of tinplate (1·5 lb. of tin per basis box, 16·8 g. per sq. m.) in the boiling liquid and determining the loss in weight with increase in time of immersion. The treatment was stopped when the loss in weight reached a constant value, and the specimen was then dissolved in hydrochloric acid and the remaining (alloyed) tin determined in the usual way; blank tests were carried out on the steel base.

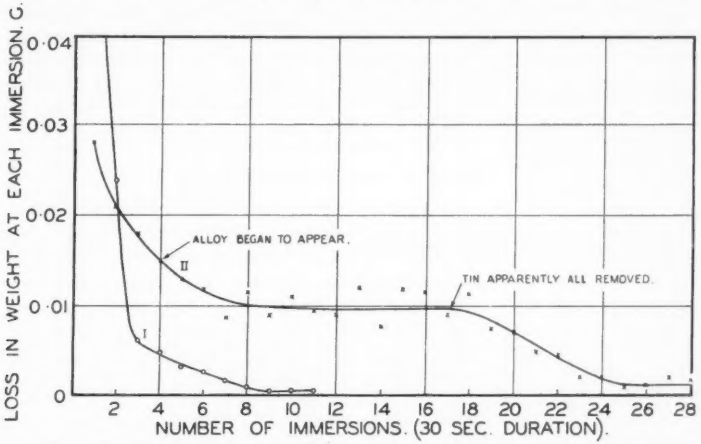
Unsuitable proportions of sodium hydroxide and lead acetate were found to result in a solution which was either unstable (with too little alkali) or which markedly attacked, and sometimes completely removed, the alloy layer (with too much alkali). With low concentrations of lead, the solution was very slow in dissolving the tin coating, and appreciable attack of the alloy layer took place; the lead deposited by immersion on the tinplate tended to adhere, and was more difficult to remove by swabbing than the loose precipitate obtained with solutions more concentrated in lead. At temperatures below the boiling point, the solution tended to be very slow in action.

The best results were therefore obtained by using a boiling solution with a fairly high concentration of lead and only just sufficient alkali to prevent precipitation of basic lead compounds. A suitable solution was prepared by adding, with vigorous stirring, a solution of 80 g. of lead acetate in 500 c.c. of water to one containing

[1] *Industrial and Engineering Chemistry*, 1927, vol. 19, p. 514.

135 g. of sodium hydroxide in 500 c.c. of water. This solution was stable and rapid in action; the lead deposited by immersion was powdery and did not adhere to the tinplate. The time required for detinning with this solution was found to vary with different specimens; specimens carrying less than about 5 lb. of tin per basis box (56 g. per sq. m.) generally required 3–5 min.

A loss-in-weight/time curve for a specimen of tinplate, 10 × 7·5 cm. in size, and carrying 1·5 lb. of tin per basis box, is given in Fig. 1 (curve I.). The majority of the tin coating was removed during the first 2 min.; it was completely removed in 4·5 min., and thereafter



Curve I.—Boiling Sodium Plumbite Solution. (Sodium hydroxide 135 g., lead acetate 80 g., water 1 litre.)

Curve II.—Dilute *Aqua Regia*. (HCl 20 c.c., HNO_3 5 c.c., water 75 c.c.) Room temperature.

FIG. 1.—Detinning of Tinplate, 1·5 lb. per basis box.

the loss in weight, representing slight attack of the alloy layer, was constant and equivalent to a loss of 0·1 oz. of alloyed tin per basis box (0·07 g. per sq. m.) per min. (3% per min. of the average quantity of alloyed tin present on coke-quality tinplate). It is therefore important that the time of treatment should not be prolonged more than is necessary.

The following procedure has been found satisfactory:

The specimen is degreased by swabbing with an organic solvent, and is then dried, weighed, and immersed in a boiling solution of sodium plumbite, prepared as described above. After 2 min. the specimen is removed, thoroughly washed, and swabbed with wet cotton wool to remove precipitated lead, dried, and reweighed. The treatment is repeated with periods of immersion of 1 min. until the

loss in weight is less than 0·001 g. per sq. dm. of surface (counting both sides). The first period of immersion is, of course, extended if undissolved tin can be seen on the specimen.

When the weight of alloyed tin is required to be determined only approximately, time may sometimes be saved without undue sacrifice of accuracy by extending the initial period of immersion to 5 min. and neglecting subsequent immersions if the tin is seen to be all removed.

Detinning in Acid Solution.

A solution containing 20 c.c. of concentrated hydrochloric acid, 5 c.c. of concentrated nitric acid, and 75 c.c. of water was found to have a progressive effect on both free and alloyed tin, although the action on the alloyed tin was less rapid. There was no well-defined indication of the complete removal of either free or alloyed tin (*see* Fig. 1, curve II.). This solution is not, therefore, suitable as a detinning medium when it is desired to preserve the alloy layer intact.

Electrolytic Detinning.

Investigation showed that tin could be removed from tinplate, with little or no attack of the alloy layer, by anodic treatment in sodium hydroxide solution, provided that the temperature, potential,

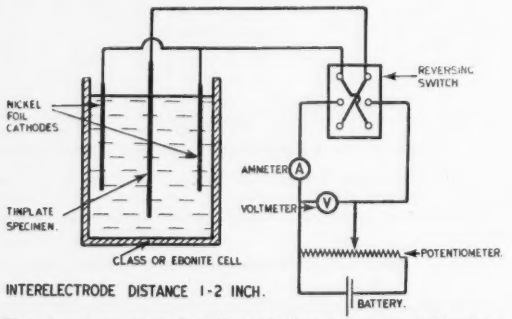


Fig. 2.—Apparatus for Electrolytic Detinning of Tinplate.

and concentration of alkali were suitably controlled. The following method was found satisfactory:

The tinplate specimen is carefully freed from grease, the methods recommended in connection with porosity testing being found suitable. It is suspended centrally between two parallel electrodes of nickel foil or iron sheet (of similar size to, or slightly smaller than the specimen) in a 5% solution of sodium hydroxide maintained at about 30° C. A diagram showing the arrangement and the electrical connections is given in Fig. 2. The specimen is first made the cathode for 1–2 min. at 0·5–1·0 V. The current is then reversed

to make the tinplate the anode, and its surface is lightly brushed to remove gas bubbles (a wad of cotton wool attached to a metal wire is suitable for this purpose). The current is controlled at 0·3–0·5 amp. per sq. dm. (3–5 amp. per sq. ft.) and the voltage should not exceed 0·5 V. (it is usually 0·2–0·3 V.) As soon as the majority of the free tin coating is removed, the voltage will begin to rise; it should be prevented from exceeding 1·0 V., and when this value is reached the current should be reversed for about a minute to make the specimen the cathode and then restored to its previous direction, care being taken to keep the voltage below 1·0 V. while the specimen is the anode. After 2 min. at a voltage of 1·0 V. the specimen should be removed, washed, and dried. The time of treatment varies with the thickness of tin coating; 10–20 min. are usually required for specimens carrying less than 3 lb. of tin per basis box.

Notes.—(1) A new solution should be used for each specimen unless the ratio of the volume of solution to the area of the specimen is very large; with increasing concentration of tin in the solution an increasing amount of spongy tin is deposited when the specimen is treated as the cathode.

(2) Small isolated areas of tin occasionally remain on the specimen after treatment, more especially with specimens having a very heavy tin coating. Several reversals of current may be necessary to remove these traces of tin, which are probably due to a passive condition caused by a high potential. The final traces of tin are removed more readily if the current is reduced to a low value in the final stages of treatment to maintain the potential difference at about 0·2–0·3 V. The difficulty is likely to be greater if the alkali content of the solution is below the recommended value, and it is sometimes necessary, when treating heavily coated specimens in a relatively small volume of solution, to renew the solution towards the end of the treatment.

(3) Hydrogen bubbles tend to cling tenaciously to the specimen after cathodic treatment, and if they are not removed small circular areas of tin will remain on the specimen where the surface has been shielded by the bubbles.

(4) The concentration of sodium hydroxide, although not critical, is preferably about 5%. High concentrations favoured attack of the alloy layer; with low concentrations the process was slow because a low current density had to be used to prevent the tin from becoming passive.

Tests of the Electrolytic Method.—With no limitations of temperature or potential it has been found possible to remove both free and alloyed tin completely from tinplate by anodic action in sodium hydroxide solution. Thus in a 5% solution of sodium hydroxide at 75° C., using a current density of 1·1 amp. per sq. dm. (10 amp. per sq. ft.) throughout the treatment, the tin coating was entirely removed from a specimen of tinplate (1·5 lb. of tin per basis box) in less than 30 min.

Preliminary tests of the effects of temperature and potential on the decomposition of the alloy layer were made, using tinplate from which the tin coating had been removed in sodium plumbite solution; the specimens were placed in the electrolytic cell and treated under various conditions of potential and temperature, the effect on the weight and appearance of the specimen being noted.

The alloy layer was found to be practically immune from attack at 15° C. with a p.d. of 1 V. across the cell; in 30 min. the loss in weight of a specimen 9 cm. square was less than 0·0005 g. (equivalent to about 1% of the average weight of alloyed tin on coke-quality tinplate). But these conditions are not entirely suitable for practical use owing to the tendency of the tin coating to become passive. At 30° C., however, the tin dissolved without trouble at current densities of 0·5 amp. per sq. dm. (5 amp. per sq. ft.) or less. The attack on the alloy layer at 30° C. with a p.d. of 1 V. was slightly more pronounced than at 15° C., amounting to a loss of 0·0025 g. on a specimen 9 cm. square in 30 min., or about 7% of the average weight of alloyed tin on a coke tinplate. Since the time for which the alloy layer is normally exposed to anodic attack at the relatively high p.d. of 1 V. is less than 5 min., this degree of attack may be regarded as negligible; it will be noted that it is appreciably less than the attack on the alloy by the boiling sodium plumbite solution of the composition recommended, which amounted to about 3% per min. of the average weight of alloyed tin on coke tinplate.

At higher temperatures (45° C.) and higher voltages (2 V.) the attack on the alloy layer was more pronounced, resulting in the formation of rust on the specimen with prolonged treatment.

Examination of the Alloy Layer on Commercial Tinplate.

Samples of commercial tinplate, 9 cm. square, were stripped of free tin by both the sodium plumbite and the electrolytic method, and the alloyed tin was determined by dissolving the specimen in hydrochloric acid and estimating the tin volumetrically in the usual way. Blank tests on the steel were done by stripping off the whole of the tin coating by immersion in the hydrochloric-acid/antimony-trichloride reagent,[1] rubbing down the surface with emery paper to remove possible traces of tin, and dissolving the steel base in hydrochloric acid. Other specimens were examined after removal of free tin for porosity, appearance, and microstructure.

Some of the specimens used in these tests were obtained from stock and were of miscellaneous manufacture; others were obtained direct from certain tinplate manufacturers.

Weight of Alloyed Tin.—The results of tests are summarised in Table I. The accuracy of the tests is indicated by the following data:

[1] S. G. Clarke, "A rapid test of the thickness of tin coatings on steel." *Analyst*, 1934, vol. 59, p. 525.

Minimum weight of free tin . . . . . 0·1290 g.
Maximum weight of free tin . . . . . 2·3985 g.
Minimum weight of alloyed tin. (Amount of $N/6$ iodine required : 5·05 c.c., less 1·8 c.c. blank on steel base) . . . . 0·0325 g.
Maximum weight of alloyed tin. (Amount of $N/6$ iodine required : 20·5 c.c., less 0·8 c.c. blank on steel base) . . . . 0·1970 g.

It will be seen from Table I. that although tinplate carrying less than about 2 lb. of tin per basis box (22·4 g. per sq. m.) has a fairly constant weight of alloyed tin, averaging 3·3 oz. per basis box (2·3 g.

TABLE I.—*Weight of Alloyed Tin on Tinplate of Various Qualities.*

Approximate Grade of Plate. Lb. of Tin per Basis Box.	Manufacturer *A*.		Manufacturer *B*.		Manufacturer *C*.		Stock Specimens, Miscellaneous Origin.	
	Total Tin Yield. Lb. per Basis Box.	Alloyed Tin. Oz. per Basis Box.	Total Tin Yield. Lb. per Basis Box.	Alloyed Tin. Oz. per Basis Box.	Total Tin Yield. Lb. per Basis Box.	Alloyed Tin. Oz. per Basis Box.	Total Tin Yield. Lb. per Basis Box.	Alloyed Tin. Oz. per Basis Box.
< 2							0·91 0·90 1·84 1·84 1·19 1·31 1·66 1·76	*2·9E* *2·9E* *3·9E* *3·8E* *3·1P* *2·9P* *3·5P* *3·2P* Average *3·3*
2–4	2·95 2·46	*4·8* *4·7E*	3·06 3·12	*12·8E* *13·5E*			3·75	*4·0P*
4–7	5·71 6·30	*3·6E* *3·4E*	4·50 4·54 3·63	*11·1E* *11·0E* *10·4P*	4·80 4·82	*9·6E* *9·7E*	4·88 4·32 4·59 4·98 4·75	*4·1P* *4·1P* *12·0E* *12·2E* *10·7P*
7–10					8·31 8·61	*9·7E* *9·4E*		
>10	12·97 13·51	*3·7E* *3·7E*	14·23 13·64	*11·4E* *12·0E*			10·83 10·62	*17·2E* *17·2E*

E = detinning by electrolytic method. P = detinning by sodium plumbite method.

Notes: (*a*) 1 lb. of tin per basis box = 11·2 g. of tin per sq. m.
1 oz. of tin per basis box = 0·7 g. of tin per sq. m.
(*b*) The bracketed figures were obtained from specimens cut from different parts of the same sheet.

per sq. m.)—a figure which is in close agreement with previously quoted data [1]—plates with heavier tin coatings may carry up to 1 lb. or more of alloyed tin per basis box (11·2 g. or more per sq. m.); 11–12 oz. of alloyed tin per basis box is not unusual. It is also interesting to note the similarity of the figures for alloyed tin on plates of widely different tin yield made by the same manufacturer (*A* and *B*). The low figure of 3·7 oz. of alloyed tin per basis box with a total tin yield of 13 lb. per basis box (manufacturer *A*) is noteworthy.

[1] Kohman and Sanborn, *loc. cit.*; S. G. Clarke, *loc. cit.*

Structure and Appearance of the Alloy Layer.—All the specimens examined which carried about 3 oz. of alloyed tin per basis box exhibited a typical mottled pattern after detinning by either the sodium plumbite or the electrolytic method (*see* Fig. 3, Plate XVIII.). The alloy layer of specimens carrying a large amount of alloyed tin (more than about 10 oz. per basis box) was free from mottle; the pattern of the tin crystals was faintly visible, and parallel lines which appeared to correspond to the grease lines could just be seen (Fig. 4).

Areas of the two types of alloy layer were selected at random and examined under the microscope. No very marked difference in the size of the $FeSn_2$ crystals was observed, but the crystals were somewhat larger on the plate carrying the heavier alloy layer, a photomicrograph of which is given in Fig. 5.

Porosity of the Alloy Layer.—Hot-water porosity tests and ferroxyl paper tests were made on some samples of tinplate detinned by the sodium plumbite and the electrolytic methods. Both methods of detinning gave similar results, and the degree of porosity indicated by the ferroxyl test was comparable with that given by the hot-water test.

The hot-water test was continued only for sufficient time (generally 15–30 min.) to develop small rust spots. After more prolonged immersion, many of the specimens were so extensively rusted that it was found difficult to locate the pores. A count of the number of pores was made on a small area; for example, a square, 1 cm. × 1 cm. in size, was ruled on the tested specimen with a sharp steel point, and this square was then subdivided into small squares about 2 mm. × 2 mm. in size; the number of pores in each square was counted under the microscope. Owing to the smallness of the area examined, the results, when calculated as in Table II. on an area of 1 sq. dm., are liable to considerable error, and are only included to give an approximate idea of the relative magnitude of the porosity compared with that of the complete tin coating. It should be noted, however, that the pores in the alloy layer of tinplate of average quality (1·5–2·0 lb. of tin per basis box) appeared to be fairly evenly distributed.

TABLE II.—*Approximate Porosity of the Alloy Layer (Hot-Water Test).*

Weight of alloyed tin. Oz. per basis box .	2·9	3·1	2·9	13
No. of pores per sq. dm. . . .	30,000	70,000	60,000	4,000
Method of detinning	Plumbite	Plumbite	Electrolytic	Electrolytic

The appearance after the hot-water test of an alloy layer having about 60,000 rust spots per sq. dm. is shown in Fig. 6.

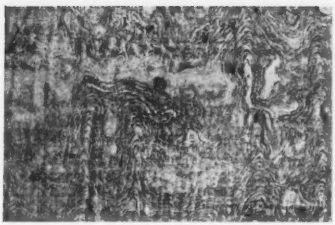


FIG. 3.—Typical Alloy Layer on Coke Tinplate. × 1.

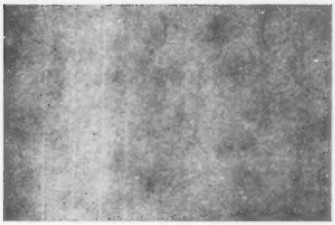


FIG. 4.—Alloy Layer carrying 13 oz. of Tin per Basis Box. × 1.

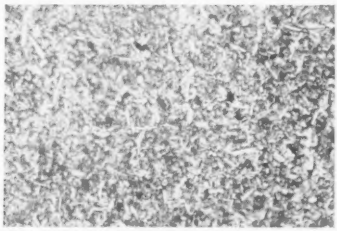


FIG. 5.—Heavy Alloy Layer (13 oz. of tin per basis box). × 500.

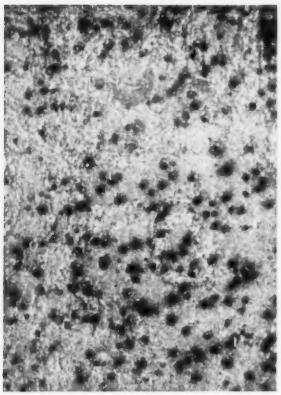


FIG. 6.—Alloy Layer of Coke-Quality Tinplate after 15 min. in Hot-Water Test (60,000 pores per sq. dm.). × 10.

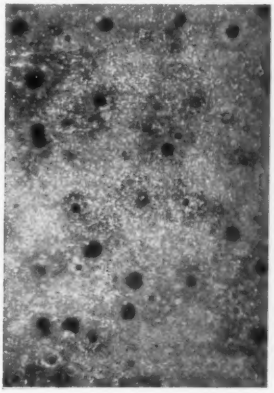


FIG. 7.—Heavy Alloy Layer (13 oz. of tin per basis box) after 60 min. in hot-water test (4000 pores per sq. dm.). × 10.

(Micrographs reduced to two-thirds linear in reproduction.)

[*Hothersall and Bradshaw.*

[*To face p.* 232 P.

With increase in the weight of alloyed tin, the number of pores decreased, and in the specimens examined their distribution was less regular. Thus, the specimen carrying 13 oz. of alloyed tin per basis box developed about 4000 pores per sq. dm. on one side, but was less porous on the other side; the appearance after the hot-water test of the more porous side of this specimen is depicted in Fig. 7. This plate was immersed in the hot water for a longer time than the plate shown in Fig. 6, and the rust spots were consequently larger. A specimen having 9 oz. of alloyed tin per basis box appeared to be intermediate in porosity.

Discussion of Results.

The results given by Kohman and Sanborn (*loc. cit.*) for commercial tinplate carrying 1–3·6 lb. of tin per basis box, using the sodium plumbite method of detinning, revealed an average amount of alloyed tin which was almost identical with that found in the present work for tinplate carrying less than about 2 lb. of tin per basis box (*i.e.*, 3·3 oz. of alloyed tin per basis box).

The average time of immersion of sheets in a tinpot during normal production is given by Kohman and Sanborn as 11 sec. The amount of alloyed tin was found by them to be increased by extending this time, the maximum recorded being about 1 lb. of alloyed tin per basis box after immersion for 60 min. in tin at 316° C. From the relatively slight increase in the rate of alloy formation which Kohman and Sanborn found with increasing time of immersion, little variation would be expected in the amount of alloyed tin on sheets tinned in the normal way by passing once through the tinpot. It is, therefore, not surprising to find such good agreement as was obtained between the results given in this paper and those recorded by Kohman and Sanborn (*loc. cit.*) and by Clarke (*loc. cit.*) for this type of tinplate.

To produce heavier coatings of tin in practice, the plate may be re-immersed for a further period in molten tin, thus increasing the thickness of the alloy layer. Since the results of the present work show considerable variation in the amount of alloyed tin with heavy tin coatings, it is evident that practice varies in respect of the time or the temperature of this further immersion.

Note on Determination of Tin Yield by Loss in Weight.

The method proposed by Clarke (*loc. cit.*) for the determination of the tin yield by the loss in weight after the dissolution of both free and alloyed tin in hydrochloric acid containing antimony trichloride as the restrainer involves the use of a correction factor for the amount of iron removed by decomposition of the alloy layer and by the slight attack of the reagent on the steel base. Both Clarke and Kohman and Sanborn found with commercial plates an approximately constant amount of alloyed tin equal to about 3 oz.

of tin per basis box (2·1 g. per sq. m.). Clarke therefore proposed a constant correction factor which amounted to 1 oz. per basis box (0·7 g. per sq. m.), and was composed of 0·7 oz. due to decomposition of the alloy layer and 0·3 oz. due to attack of the steel base. When the amount of alloyed tin exceeds 3 oz. per basis box, however, the result obtained by Clarke's method would be too high by 0·7 oz. for every additional 3 oz. of alloyed tin (0·49 g. per sq. m. for every additional 2·1 g. per sq. m. of alloyed tin).

The effect of variation in the amount of alloyed tin on the tin yield in Clarke's method, calculated on the basis of the present work, is shown in Table III.

TABLE III.—*Effect of Alloy Layer on Tin Yield in Clarke's Method.*

Total Tin. Lb. per Basis Box.	Alloy Tin. Oz. per Basis Box.	Positive Error in Clarke's Method, after making recommended deduction of 1 oz. per basis box.	
		Oz. per Basis Box.	Percentage of Total Tin Yield.
< 3	3	Nil	Nil
3–6	4	0·2	0·4–0·2
	10	1·6	3·3–1·7
	15	2·8	5·8–2·9
6–10	4	0·2	0·2–0·1
	10	1·6	1·7–1·0
> 10	4	0·2	< 0·1
	12	2·1	< 1·3
	17	3·3	< 2·0

It is thus only in the extreme case of tinplate with a moderate weight of tin (in the neighbourhood of 3 lb. per basis box) and a heavy alloy layer (15 oz. per basis box), that the positive error can amount to 5–6%. With this heavy alloy layer, the percentage positive error falls off as the total tin increases. The average grade of tinplate (less than 3 lb. per basis box) carries an amount of alloyed tin similar to that found by Clarke and by Kohman and Sanborn.

DISCUSSION.

Dr. R. H. GREAVES (Woolwich) said he had nothing to say in criticism of the paper, but there were one or two points which he would like to emphasise. It must be remembered that the alloy layer was very thin, a matter of a hundred-thousandth of an inch or so, and therefore he thought that the authors were to be congratulated on having obtained a method by which they could remove the tin surface so cleanly, and then examine the underlying layer. The use of that method had revealed one feature which he did not remember seeing recorded before, namely, that in certain makes of tinplate, either intentionally or as an unintentional result of the methods of manufacture, the alloy layer was very much thicker than in other makes. That raised the question of the most desirable thickness of the alloy layer and how it might be controlled. A thick alloy layer would be likely to reduce porosity; on the other hand, the alloy layer was brittle, and a thick alloy layer was more likely to be ruptured on bending the plate, so damaging the surface. He hoped, therefore, that the work which the authors had carried out on the method of exposing the layer would be followed up by work on the influence of conditions of pickling and of fluxing on the thickness of the layer, and after that on the effect of the thickness of the layer on the quality of the plate produced.

Mr. W. E. HOARE (London) said the authors had carried out a piece of work which was going to be of very great value to anyone who was concerned with the examination of tin coatings, and he would like to thank them for the help that they had given him personally in that direction. The authors would probably agree that during the past three years there had necessarily grown up new techniques for examining tinplates due to the extreme thinness of the tin coating and the alloy layer. Of all those new techniques, possibly the method of selective detinning had given more information than any other. Now, owing to the industry of the authors, it was possible to use that method of selective detinning and have a full knowledge at the same time of the correct conditions and the limitations.

The first point which he would like to raise was that concerning the use of dilute *aqua regia* for detinning. The authors dismissed that reagent in a few words, but personally he would like to uphold it a little on the ground of its great convenience. Boiling in sodium plumbite was all very well with a piece of material 3 in. square, but with a 20 × 28-in. sheet he would prefer dilute *aqua regia*, and, if it were used carefully, a good deal of information could be obtained by its use, particularly when microscopical or macroscopical examination was the aim, rather than the analytical estimation of the amount of compound present.

Like Dr. Greaves, he had found the chief interest of the paper in the figures quoted in Table I., and it was extremely interesting to see that there were two procedures for obtaining heavy tin yields. One of them, he thought, must be the method of different setting of the tin-pot rolls. One manufacturer, *A*, obtained an alloy tin yield of about 3·7 oz., while another manufacturer, *B*, obtained a yield of something like 1 lb. for the same tin yield. Details of the types of tin-pots used by manufacturers *A* and *B*, if the authors had them, would be interesting. Evidently manufacturer *A* relied entirely on the setting, whereas *B* was giving his plates a long soak. The relative properties of those two types of coating, one containing much and the other containing little alloyed tin, would be interesting, and if the authors had any results they might perhaps be given later. The first consideration in the case of manufacturer *B* would be that he was getting less of the tin coating which was on his sheet, and for which his customer paid, in the form of ductile coating, and more in the form of brittle metal. That was one obvious disadvantage. Another consideration, in the opposite sense, was the fact that the porosity of the alloy layer produced by *B* was, as the authors had shown, very much less. Those two points emerged from the paper, and the examination of those two types of coating would, he thought, yield many more.

AUTHORS' REPLY.

Mr. HOTHERSALL, in reply, said the authors were grateful to Dr. Greaves. It was always rather an uninteresting job to describe a method, but in the particular instance in question the method had a very important application as a research tool, and it was gratifying to see that ways in which it might be useful had been appreciated by both the contributors to the discussion.

Mr. Hoare had referred to the valuable evidence obtained by selective detinning. It might be mentioned, in connection with the statement in the paper by Hothersall and Prytherch (also presented at the meeting) that the tin coating in the area of the scruff bands was thinner than elsewhere, that detinning by the method of anodic dissolution of the tin had given further proof of this local thinness, because when a tinplate was treated anodically under controlled potential the tin stripped first of all in the area of the scruff bands, and one saw the bands gradually developing up, because the colour of the compound layer underneath differed from that of the tin coating.

The authors recognised that *aqua regia* was a very useful reagent for the examination of tinplate, but their results, he thought, definitely showed that where it was desired, or essential, to leave the alloy layer intact, *aqua regia* was not of any value.

With regard to the details of manufacture of the three tinplates called *A*, *B*, and *C*, he was afraid that the authors had none to give. They had felt that in that direction they might enter on dangerous ground, and that a lot more data on the advantages or disadvantages of a thick alloy layer were desirable before entering into details of methods of manufacture. It was known, however, that the tinplates concerned were produced at three different works.

FACTORS INFLUENCING THE RATE OF ATTACK OF MILD STEELS BY TYPICAL WEAK ACID MEDIA.[1]

By T. P. HOAR, M.A., Ph.D. (Cambridge), and D. HAVENHAND, B.Sc. (Sheffield).

Summary.

Several important factors influencing the rate of corrosion of steel in citric acid and citrate buffers have been elucidated and their mechanism studied. Corrosion decreases with increase of *p*H from 1·98 to 4·89. In the more acid solutions, corrosion is accelerated by sulphur in the metal or in the solution owing to stimulation of the anodic process by dissolved sulphide. It is retarded by tin (and cadmium) ions, which remove soluble sulphide, and by copper in the metal, which probably also removes sulphide. The presence of massive cementite in the metal may accelerate corrosion by assisting the cathodic process. In the less acid solutions all these effects are diminished, and the supply of oxygen becomes an important factor.

The necessity of electrochemical measurements and theories in the elucidation and interpretation of the factors influencing corrosion is emphasised.

The practical implications of the work are pointed out. It is suggested that steel for use under conditions of acid corrosion, such as the steel-base of tinplate, should preferably be rimming steel having a copper content not less than twice the sulphur content.

Introduction.

The corrosion of iron and steel by acids has received less adequate study than the corrosion by neutral saline media, probably because the cases of acid corrosion which occur under service conditions are the less in evidence. Nevertheless, besides its theoretical interest, attack by acids is of great practical importance; examples are the corrosion of steel structures in acid atmospheres, and, particularly, the corrosion of the tinned steel can used for packing acid food-stuffs, which latter problem has given rise to the present research.

It is well recognised that different varieties of mild steel corrode at widely different rates in dilute mineral acids. Much has been written and little proved with regard to the effect of chemical composition on the rate of attack. Carbon up to 0·2% seems to have a comparatively small accelerating influence. Silicon up to 0·2% appears to have little or no effect. Sulphur, as emphasised by Stead,[2] has long been thought to have an important accelerating

[1] Received February 5, 1936.

[2] J. E. Stead, *Journal of the Iron and Steel Institute*, 1916, No. II., p. 5.

influence, a view confirmed by Endo [1] for high-sulphur steels. The latter author also found that a high phosphorus content stimulates acid attack. The general effect of copper on steel corrosion, early referred to by Stead and Wigham,[2] has been the subject of long controversy, but a review of the literature [3] seems to establish at least that amounts of copper such as 0·2% and even less greatly retard the attack by dilute sulphuric acid. There is at present no evidence that manganese, chromium, nickel, and arsenic in the amounts ordinarily present in mild steel have any considerable effect on its corrosion by acids, and the contention of Auperle [4] that a high oxygen content increases such attack rests on insecure experimental grounds. The effect of structure has been little investigated; Guthrie,[5] however, found that the core of a rimming steel was more susceptible to corrosion than the rim, ascribing the effect (without evidence) to the greater spheroidisation of the cementite in the rim.

Recently, Morris [6] and Morris and Bryan [7] have investigated the attack of white-annealed dead-mild steel-base—such as is used in the manufacture of tinplate—by dilute citric acid and citrate buffers, used in imitation of the fruit acids likely to come into contact with such material in practice. They found very large variations in the corrosion rate of different samples of steel-base. They also studied the effect of traces of sulphur [8] and of tin ions [9] in the corroding medium, showing that sulphur (as sulphur dioxide or hydrogen sulphide) has a marked accelerating effect in acid media, whereas tin ions exercise a retarding influence.

The present research was designed to discover important factors influencing this type of attack, and to elucidate the mode of operation of such factors. It is believed that the value of laboratory corrosion work lies, not in the performance of dubious empirical "accelerated tests" designed to mimic yet speed-up practical conditions, but in the elucidation of the *mechanism* of the various kinds of attack, the theory of which can then be applied with due caution to practical cases. With this in view, the attack

[1] H. Endo, *Science Reports of Tôhoku Imperial University*, 1928, vol. 17, p. 1245.

[2] J. E. Stead and F. H. Wigham, *Journal of the Iron and Steel Institute*, 1901, No. II., p. 122.

[3] For references see Bibliography of Copper Steels, *First Report of the Corrosion Committee, Iron and Steel Institute, Special Report No.* 1, 1931, p. 221.

[4] J. A. Auperle, *Proceedings of the American Society for Testing Materials*, 1911, vol. 11 (2), p. 614.

[5] R. G. Guthrie, *Transactions of the American Society for Steel Treating*, 1927, vol. 11, p. 341.

[6] T. N. Morris, *Report of the Food Investigation Board*, 1931, p. 183.

[7] T. N. Morris and J. M. Bryan, *ibid.*, 1933, p. 149.

[8] T. N. Morris and J. M. Bryan, *ibid.*, 1928, p. 62; T. N. Morris, *ibid.*, 1930, p. 119.

[9] J. M. Bryan, *ibid.*, 1930, p. 109; T. N. Morris and J. M. Bryan, *Transactions of the Faraday Society*, 1932, vol. 29, p. 395.

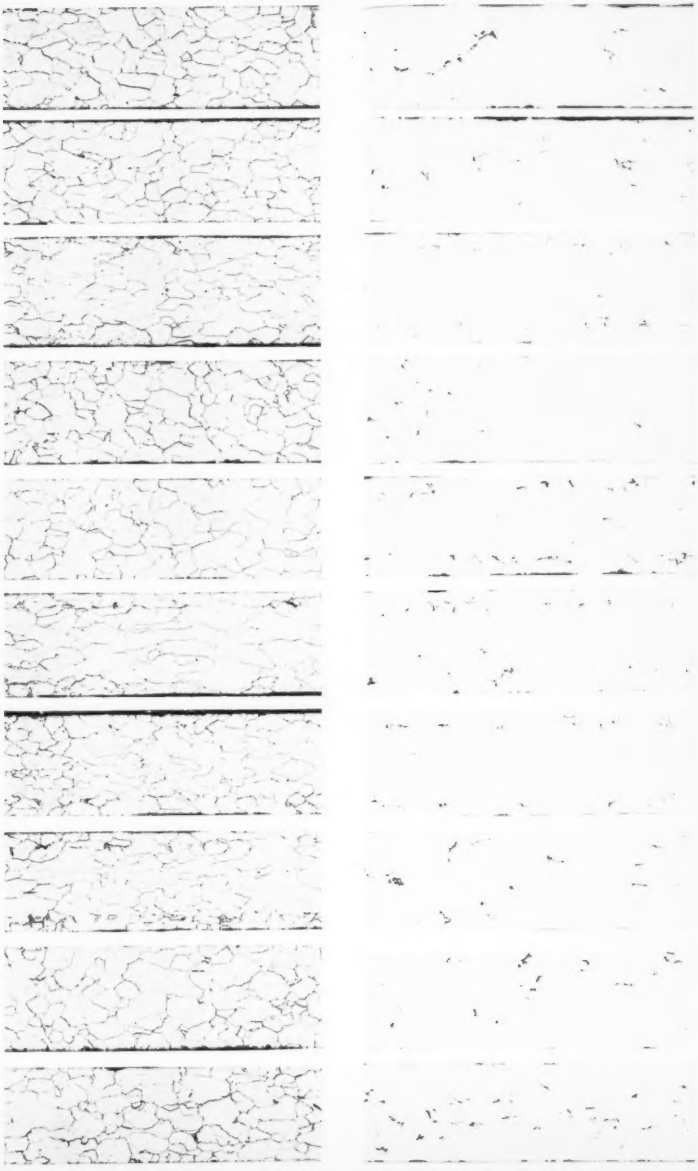


FIG. 1A.—Microstructure of Materials. (Section in direction of rolling.) × 50.

[*Hoar and Havenhand.*

[*To face p.* 240 P.

Etched in 2% Alcoholic HNO_3. *Etched in Alkaline Sodium Picrate.*

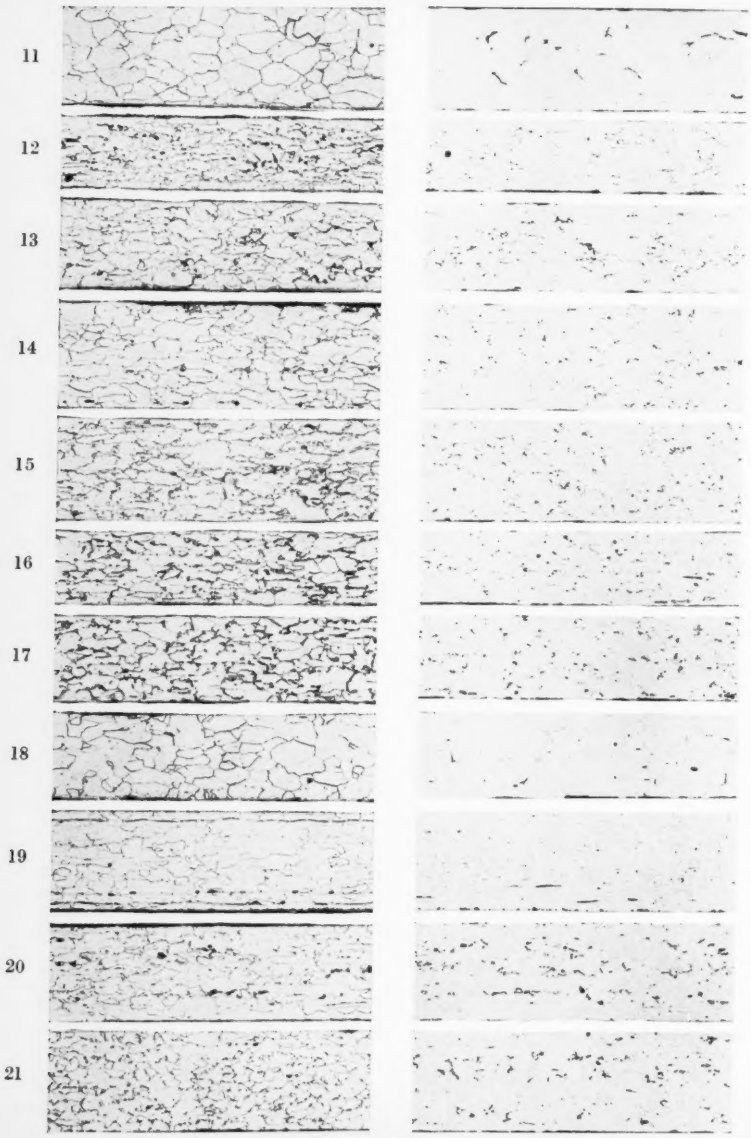


FIG. 1B.—Microstructure of Materials. (Section in direction of rolling.) × 50.

[*Hoar and Havenhand.*

Etched in 2% Alcoholic HNO_3. *Etched in Alkaline Sodium Picrate.*

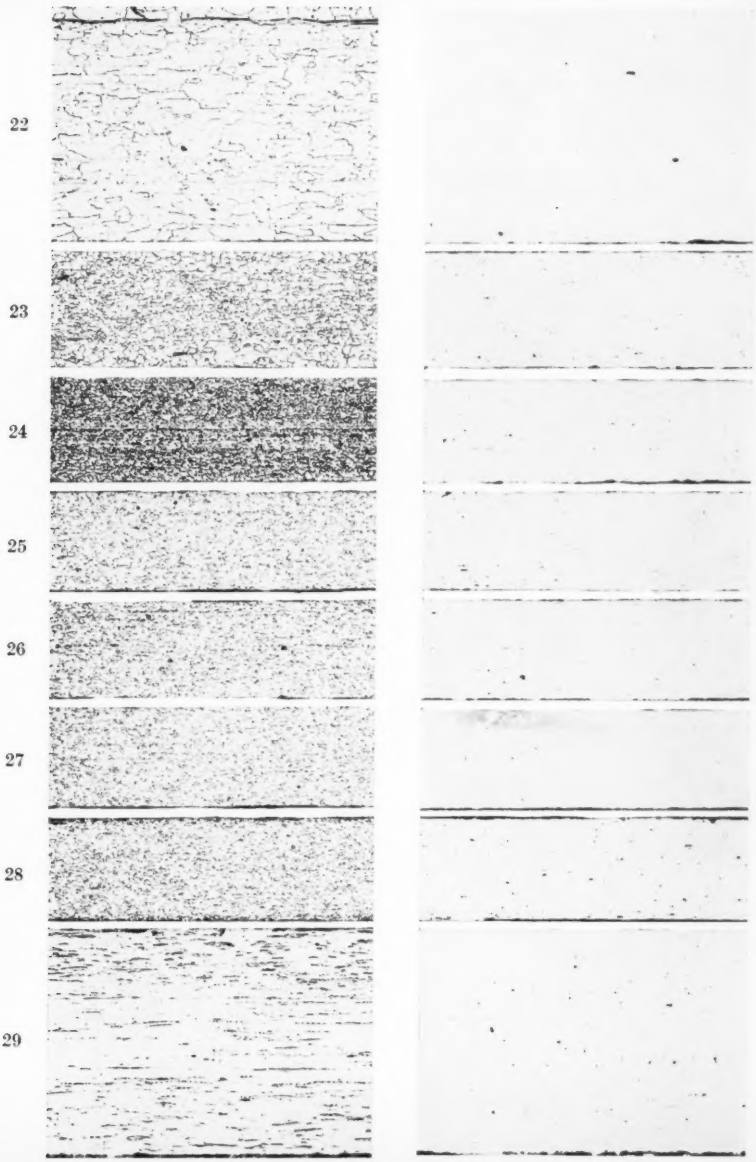


FIG. 1c.—Microstructure of Materials. (Section in direction of rolling.) × 50.

[*Hoar and Havenhand.*

Etched in 2% Alcoholic HNO_3. *Etched in Alkaline Sodium Picrate.*

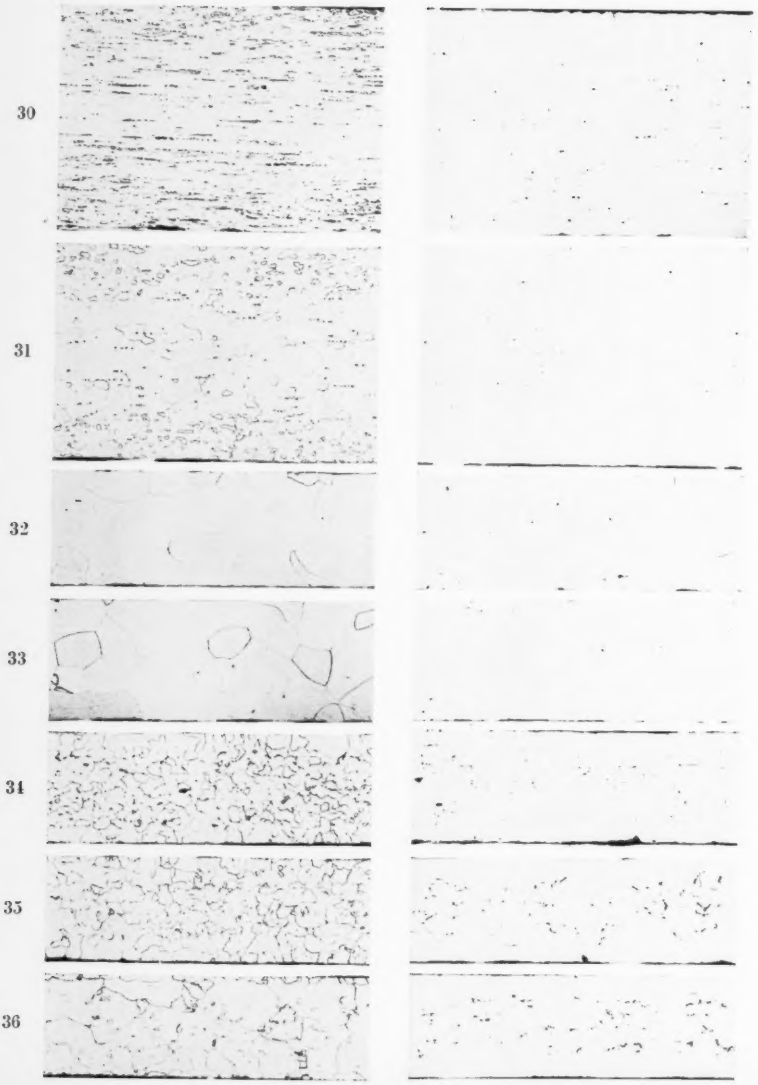


FIG. 1D.—Microstructure of Materials. (Section in direction of rolling.) × 50.

[*Hoar and Havenhand.*

[*To face p.* 241 P.

by citric acid and citrate buffers of thirty-six different varieties of iron and dead-mild steel, mainly of the tinplate type, has been studied gravimetrically and electrochemically under simple conditions, the results being correlated with the chemical and metallographic analysis of each material. The effects of traces of sulphur, and of tin and other metal ions, in the corroding media have also been investigated. The main result established is that sulphur in steel has a pronounced accelerating effect under these conditions, but that this acceleration is entirely counteracted by the presence of approximately twice as much copper as sulphur in the metal, and is partially suppressed by small amounts of tin ions in the corroding media. A simple yet comprehensive theory is developed to account for these and other phenomena, and possible applications to practice are indicated.

Experimental.

Materials.—Analyses and descriptions of the irons and steels are given in Table I., while Figs. 1A, 1B, 1C, and 1D (Plates XIX. to XXII.) show microsections of each material, obtained as hereafter described. Materials Nos. 1 to 17 were furnished through the courtesy of Mr. T. N. Morris of the Low-Temperature Research Station; materials Nos. 32 and 33 were kindly presented by Dr. U. R. Evans, and the remainder were obtained from various sources through the organisation of the International Tin Research and Development Council.

The materials were abraded with No. 1*G* Hubert emery paper sufficiently to remove the oxide scale, if any, but lightly enough to remove only a very small fraction (about 0·005) of the metal thickness. Each material was cut into specimens 6·5 × 2·5 cm., the edge portions of strip and all the blued edges of white-annealed sheets being rejected as being not typical of the material. The specimens were stored in dry air until required.

Citric acid, alone and buffered with sodium citrate, was chosen as the corroding medium for a number of reasons: (*a*) It is a typical fruit acid, such as may come into contact with mild steel in canning practice; (*b*) it is obtainable in a high state of purity; (*c*) it is readily buffered with its own sodium salt. Solutions of *p*H ranging from 1·98 to 4·89 were used, the total (ionised + unionised) citrate concentration being always 0·1*M*. They were made up from B.D.H. "Analar" materials and distilled water condensed on pyrex glass.

Metallographic Technique.—The metallographic technique employed consisted of clamping specimens of about a dozen materials together in a short piece of channel iron; they were then polished (finishing with diamantine on selvyt), etched, and photographed together. The composite nature of the block and specimens made certain precautions necessary during etching, owing to the etching reagent penetrating to some extent between the strips of steel,

TABLE I.—*Analyses and Description of Materials.*

Material No.	Thickness. Cm.	C. %.	Si. %.	S. %.	P. %.	Mn. %.	Ni. %	Cr. %.	Sn. %.	Cu. %.	Description.
1	0·030	0·042	0·017	0·017	0·025	0·320	Nil	0·039	Nil	0·015	Steel-base for tinplate; white annealed.
2	0·032	0·027	0·012	0·018	0·027	0·351	Nil	0·045	Nil	0·014	
3	0·032	0·045	0·006	0·030	0·037	0·323	Trace	Trace	Nil	0·014	
4	0·031	0·055	0·007	0·019	0·026	0·328	Nil	0·029	Nil	0·011	
5	0·030	0·033	0·006	0·042	0·056	0·368	Nil	0·022	Nil	0·007	
6	0·031	0·052	0·005	0·031	0·037	0·342	Nil	0·040	Nil	0·015	
7	0·031	0·031	0·011	0·043	0·052	0·356	Nil	0·125	<0·005	0·011	
8	0·030	0·044	0·011	0·017	0·024	0·314	Nil	0·094	Nil	0·013	
9	0·031	0·045	0·013	0·017	0·029	0·323	Nil	0·073	Nil	0·014	
10	0·029	0·065	0·006	0·026	0·042	0·383	Nil	0·047	Nil	0·010	
11	0·031	0·044	0·021	0·014	0·024	0·362	Nil	0·078	<0·005	0·014	
12	0·022	0·140	0·013	0·023	0·034	0·432	Nil	0·078	Nil	0·052	
13	0·026	0·126	0·015	0·029	0·041	0·418	Nil	0·140	Nil	0·048	
14	0·031	0·075	0·002	0·056	0·044	0·350	Nil	0·109	0·021	0·125	
15	0·031	0·129	0·007	0·032	0·032	0·426	Trace	0·043	Nil	0·051	
16	0·022	0·115	0·017	0·062	0·067	0·360	Nil	0·042	Nil	0·081	
17	0·025	0·129	0·016	0·058	0·061	0·389	Trace	0·065	<0·005	0·082	
18	0·027	0·049	0·010	0·035	0·058	0·448	Nil	0·107	Nil	0·047	
19	0·029	0·076	0·026	0·069	0·071	0·365	Trace	0·068	0·005	0·114	Steel-base from detinned tinplate.
20	0·030	0·109	0·006	0·071	0·060	0·335	Trace	0·073	0·005	0·096	
21	0·030	0·076	0·012	0·046	0·047	0·453	Trace	0·093	0·071	0·157	
22	0·073	0·071	0·009	0·021	0·026	0·383	Trace	0·029	...	0·044	
23	0·035	0·117	0·015	0·036	0·024	0·339	0·132	0·045	...	0·091	
24	0·030	0·07	...	0·049	...	...	...	...	Nil	0·010	
25	0·031	0·071	0·016	0·037	0·057	0·519	Nil	0·133	0·18	0·009	Steel strip; cold-rolled and annealed.
26	0·030	0·052	0·095	0·035	0·053	0·562	Nil	0·052	0·53	0·020	
27	0·031	0·075	0·033	0·045	0·057	0·528	Nil	0·047	0·82	0·018	
28	0·029	0·043	0·036	0·039	0·055	0·562	Nil	0·088	1·15	0·008	
29	0·067	0·025	<0·01	0·020	0·005	0·030	0·045	0·006	...	0·059	Armco iron; cold-rolled.
30	0·067	0·025	<0·01	0·020	0·005	0·030	0·045	0·006	...	0·059	As 29, but annealed in H_2 at 525° C. for ½ hr.
31	0·067	0·025	<0·01	0·020	0·005	0·030	0·045	0·006	...	0·059	As 29, but annealed in H_2 at 950° C. for ½ hr.
32	0·039	<0·03	0·004	Trace	Trace	Trace	Nil	...	...	...	Iron prepared from carbonyl.
33	0·039	<0·03	0·004	Trace	Trace	Trace	Nil	...	...	...	
34	0·033	0·094	0·020	0·030	0·029	0·432	Trace	0·119	0·031	0·080	Steel-base for tinplate; hot-rolled, annealed above Ac_3, cooled fairly rapidly.
35	0·032	0·061	0·008	0·035	0·024	0·425	Trace	0·094	0·037	0·081	Steel-base for tinplate; box-annealed above Ac_3, cooled very slowly.
36	0·036	0·051	0·014	0·036	0·026	0·423	Trace	0·130	0·065	0·083	Steel-base for tinplate; cold-rolled 10% reduction, box-annealed at 775° C., cooled slowly.

though with care in packing the strips into the channel iron this could be almost eliminated. The etching reagents used were 2% alcoholic nitric acid and alkaline sodium picrate solution. In the former case, the etched block was washed quickly with alcohol, placed in three successive baths of alcohol, and dried after a final alcohol wash. After etching in alkaline sodium picrate solution, the blocks were immersed in several batches of hot water before the final drying with alcohol.

The photographs were cut up along the dark lines indicating the slight gap and/or etching between the specimens. The series etched in alcoholic nitric acid shows mainly the grain boundaries, whilst that etched in alkaline sodium picrate shows massive cementite as black elongated patches at the grain corners and boundaries.

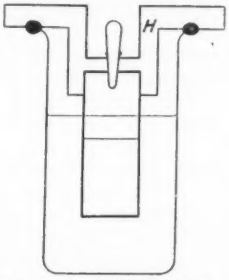


FIG. 2.—Corrosion Vessel.

Corrosion Technique.—Since it was desired to carry out a large number of comparative corrosion tests, the simple arrangement depicted in Fig. 2 was adopted. Specimens, 6·5 × 2·5 cm., were prepared 24 hr. before the experiment by further light but uniform abrasion with No. 1*G* Hubert emery paper, followed by degreasing twice with carbon tetrachloride. After being weighed, they were covered with paraffin wax for a length of 3·0 cm. from the top, leaving 3·5 × 2·5 cm. of the metal exposed. Immediately prior to the commencement of the experiment, they were fixed by means of crocodile clips to the waxed nickel-plated copper holders *H*, which were rigidly fixed to 270 c.c. beakers, 11 cm. high × 6 cm. in dia., with soft red wax. The corroding solution, at 25° C., was then run into the beakers until the top of the exposed part of the specimen was 1 cm. below the liquid-line; the holders were previously calibrated so that this depth of liquid gave a total volume of 200 c.c. The beakers and contents, thirty-six in each experiment, were then placed in a metal box, 76 cm. long × 33 cm. wide × 18 cm. high, fitted with a thick rigid wooden base and a hinged lid. The whole was contained in a small thermostat room at a mean temperature of 25·0 ± 0·05° C. The fluctuations of temperature in the air-

space of the room outside the box were $\pm$ 0·3° C., but inside the box the temperature was within the limits stated.

Immediately before the specimens were removed from the corroding liquid after the period of test, the electrode potential of each specimen was measured. One lead from a valve electrometer similar to that previously described [1] was clipped on to the specimen holder, and liquid connection with the surface of the corroding solution was made with the tip of a capillary tube leading from a quinhydrone half-cell containing quinhydrone in the same solution as that used in the test. Liquid junction potentials were thus avoided, and no mechanical disturbance of the corroding system occurred. The *p*H of the solution was found by measuring the e.m.f. of the quinhydrone half-cell coupled through a saturated potassium chloride bridge with a standard calomel half-cell.

After removal, the specimens were washed, dried, dewaxed, degreased, and weighed.

A few preliminary experiments were carried out for 24, 72, and 120 hr., and 72 hr. was thereafter chosen as a standard time of test, as being representative of the initial stages, at least, of the acid attack. The rate of attack of the materials used for this test (Nos. 23, 34, 35, and 36) was approximately constant with time.

All the thirty-six materials were then tested for 72 hr. in 0·1*M* (about 2·1%) citric acid, *p*H 1·98, (*a*) plain, (*b*) with the addition of 15 parts per million of sulphur added as sulphur dioxide, (*c*) with the addition of 15 parts per million of tin added by anodic dissolution as stannous ions. The majority were also tested in 0·1*M* sodium dihydrogen citrate, *p*H 3·64, and 0·1*M* disodium hydrogen citrate, *p*H 4·89, also under conditions (*a*), (*b*), and (*c*). Several other special runs, to elucidate particular points, were carried out, and will be described in due course. Every test was carried out in triplicate; the total number of specimens used in the work was upwards of a thousand.

Results and Interpretation.

The qualitative results may be briefly reported first. All the materials evolved hydrogen under all the conditions of corroding media used. The attack was general over the entire exposed surface, there being no evidence of any differential aeration; none would be expected under these conditions of hydrogen evolution. Certain of the materials, however, revealed in the more acid solutions a tendency to corrode more intensely at the edges than in the centre of the specimen, an effect also observed by Bryan,[2] and in a few cases streaks of more intense corrosion on the general surface occurred. These effects were not found at *p*H 4·89, nor in the more

[1] U. R. Evans and T. P. Hoar, *Proceedings of the Royal Society*, 1932, A., vol. 137, p. 343.

[2] J. M. Bryan, *Report of the Food Investigation Board*, 1930, p. 109.

acid solutions when 15 parts per million of sulphur were present. The more rapidly corroding materials often became covered with a very loose black layer, consisting of insoluble impurities.

The quantitative results, gravimetric and electrometric, of the main experiments are given in Table II. Several points are at once apparent from the gravimetric figures.

(1) There are very large differences in corrosion rate among the materials at *p*H 1·98, which become less at *p*H 3·64, and still less at *p*H 4·89.

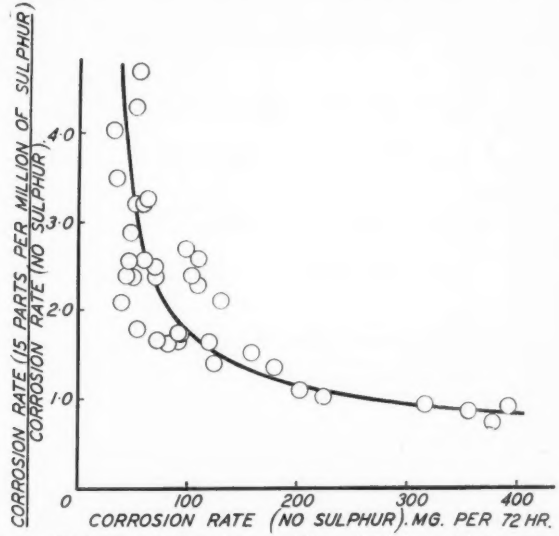


FIG. 3.—Influence of 15 parts per million of Sulphur added as SO_2 on corrosion rate in 0·1*M* citric acid.

(2) In general, corrosion decreases with decreasing acidity (the exceptions, materials Nos. 31 to 36, are discussed later).

(3) The addition of 15 parts per million of sulphur as sulphur dioxide increases the corrosion rate at *p*H 1·98 (except of the four most rapidly corroded steels), the effect being less at *p*H 3·64 and negligible at *p*H 4·89. In general, at *p*H 1·98, the smaller the corrosion rate in the plain solution, the greater the proportional effect of the added sulphur. This is indicated in Fig. 3; the ratio (corrosion with added sulphur)/(corrosion without sulphur) is seen to decrease as the corrosion rate in the plain solution increases.

Special experiments, with several of the materials, indicated that the effect of dissolved sulphur increases continuously with the amount added, at any rate up to 100 parts per million.

TABLE II.—*Corrosion Rates and Corrosion Potentials.*

See Note on opposite page.

The corrosion rates are given as weight loss in mg. per 72 hr., for specimens 3·5 × 2·5 cm.
The corrosion potentials are given in mV., referred to the reversible hydrogen electrode in the same liquid as zero. For potentials on the normal hydrogen scale, add −117 mV. at *p*H 1·98, −215 mV. at *p*H 3·64, and −289 mV. at *p*H 4·89.

Material No.	0·1*M* Citric Acid, *p*H 1·98.						0·1*M* Sodium Dihydrogen Citrate, *p*H 3·64.						0·1*M* Disodium Hydrogen Citrate, *p*H 4·89.					
	+15 parts per million of Tin.		Plain.		+15 parts per million of Sulphur.		+15 parts per million of Tin.		Plain.		+15 parts per million of Sulphur.		+15 parts per million of Tin.		Plain.		+15 parts per million of Sulphur.	
	Weight Loss in 72 hr. Mg.	Potential. mV.	Weight Loss in 72 hr. Mg.	Potential. mV.	Weight Loss in 72 hr. Mg.	Potential. mV.	Weight Loss in 72 hr. Mg.	Potential. mV.	Weight Loss in 72 hr. Mg.	Potential. mV.	Weight Loss in 72 hr. Mg.	Potential. mV.	Weight Loss in 72 hr. Mg.	Potential. mV.	Weight Loss in 72 hr. Mg.	Potential. mV.	Weight Loss in 72 hr. Mg.	Potential. mV.
1	48·2	−192	61·0	−201	201·3	−234	36·6	−166	33·0	−168	64·7	−199	31·0	−130	30·3	−130	31·0	−163
2	43·9	−193	157·2	−225	243·5	−239	28·1	−164	41·4	−184	77·7	−208	25·9	−140	25·1	−139	30·4	−171
3	38·2	−185	97·5	−208	264·0	−239	31·5	−166	41·0	−182	66·5	−208	30·5	−137	27·8	−136	26·0	−165
4	50·6	−194	177·8	−228	243·2	−240	44·0	−185	47·4	−190	72·9	−209	28·3	−144	28·6	−158	29·2	−163
5	98·9	−200	355·7	−237	308·8	−239	68·9	−192	92·1	−199	83·9	−211	28·5	−151	28·5	−164	34·9	−176
6	39·6	−186	108·0	−214	279·9	−233	43·4	−178	47·2	−187	73·7	−207	34·3	−132	30·0	−150	28·0	−164
7	106·0	−202	378·4	−228	295·0	−238	50·0	−181	73·0	−192	81·7	−204	27·0	−141	27·3	−150	35·4	−165
8	49·7	−193	90·1	−207	148·9	−233	37·8	−171	42·8	−170	66·4	−201	34·7	−128	36·3	−127	30·5	−159
9	54·3	−195	103·1	−212	247·9	−236	37·7	−172	41·4	−175	66·1	−202	34·5	−128	31·0	−135	30·4	−157
10	97·2	−201	316·4	−230	294·8	−240	53·4	−190	80·3	−198	85·8	−207	28·6	−144	27·3	−157	32·1	−165
11	55·4	−194	128·9	−220	272·8	−241	36·4	−172	43·9	−180	76·6	−205	28·5	−134	27·6	−135	32·2	−161
12	40·6	−182	51·2	−192	219·1	−228	37·2	−162	35·8	−159	83·6	−201	33·3	−126	31·5	−127	37·9	−164
13	36·5	−173	58·0	−192	185·6	−227	40·2	−158	39·9	−157	76·8	−198	41·1	−118	47·3	−119	38·6	−161
14	23·1	−163	50·1	−194	160·9	−217	24·7	−148	28·3	−159	69·6	−198	22·8	−115	24·9	−127	37·7	−162
15	39·3	−185	118·9	−214	196·4	−227	39·2	−175	53·1	−189	79·2	−207	29·3	−148	30·3	−152	36·3	−169
16	44·0	−182	108·9	−211	249·5	−227	39·5	−172	41·1	−174	79·2	−198	23·3	−138	24·5	−140	36·0	−164
17	40·8	−181	222·7	−218	227·9	−224	34·9	−174	52·3	−185	79·6	−204	24·0	−145	24·6	−150	37·6	−176
18	37·8	−178	201·5	−211	222·7	−229	37·3	−157	114·5	−192	85·8	−201	36·0	−131	34·2	−142	36·8	−169
19	43·3	−182	92·5	−204	161·2	−223	38·1	−175	43·3	−165	66·7	−205	22·9	−144	24·5	−138	33·9	−163
20	27·3	−165	80·5	−202	131·9	−218	37·0	−161	39·1	−170	55·6	−203	24·2	−129	37·2	−137	29·8	−157
21	23·0	−141	38·3	−183	80·4	−210	30·2	−140	35·9	−151	52·3	−195	24·7	−110	35·3	−119	31·1	−156
22	45·1	−184	68·6	−200	171·2	−225	...	...	37·4	−166	...	...	...	...	33·5	−130	...	...
23	40·4	−176	71·0	−190	118·5	−205	33·3	−156	36·0	−150	69·8	−189	24·2	−128	23·3	−127	37·9	−148
24	192·6	−208	392·2	−220	361·6	−235	...	...	...	...	...	...	...	...	...	...	...	...
25	125·6	−201	123·2	−205	173·7	−224	72·0	−193	69·4	−192	101·1	−214	38·0	−163	38·5	−161	53·8	−183
26	97·8	−193	68·7	−187	163·3	−216	58·7	−183	61·2	−186	95·7	−209	35·1	−158	33·9	−158	53·0	−184
27	86·2	−192	89·9	−192	157·3	−214	58·5	−183	59·0	−185	93·6	−206	35·4	−153	35·9	−157	51·0	−184
28	69·7	−187	58·7	−185	151·2	−208	46·6	−181	46·8	−181	94·0	−206	27·9	−155	28·7	−155	51·6	−186
29	35·8	−187	53·8	−193	257·0	−228	...	...	29·0	−151	...	...	...	...	22·4	−131	...	...
30	28·3	−180	42·4	−196	101·9	−215	...	...	25·2	−150	...	...	...	...	20·4	−120	...	...
31	34·2	−158	52·9	−197	94·8	−212	...	...	78·7	−160	...	...	...	...	85·8	−123	...	...
32	...	...	33·1	−160	115·8	−229	...	...	22·9	−138	48·9	−197	...	...	67·1	−131	25·9	−164
33	33·7	−166	31·1	−169	127·8	−236	42·8	−131	55·8	−142	57·6	−213	63·5	−131	71·0	−137	28·9	−185
34	28·5	−156	46·6	−176	134·4	−217	54·8	−143	49·8	−141	66·3	−201	37·4	−100	55·7	−102	32·5	−166
35	27·6	−152	45·2	−172	116·1	−216	59·5	−137	52·0	−143	56·8	−198	46·9	− 98	64·4	−112	28·0	−157
36	31·4	−153	48·9	−167	116·5	−214	70·3	−124	79·9	−140	64·9	−190	53·6	− 93	83·2	−119	30·6	−150

(4) The addition of 15 parts per million of stannous ions decreases the corrosion rate at *p*H 1·98, the effect being less at *p*H 3·64 and negligible at *p*H 4·89. In general, at *p*H 1·98, the greater the corrosion rate in the plain solution the greater the proportional effect of the added tin. This is shown in Fig. 4; the ratio

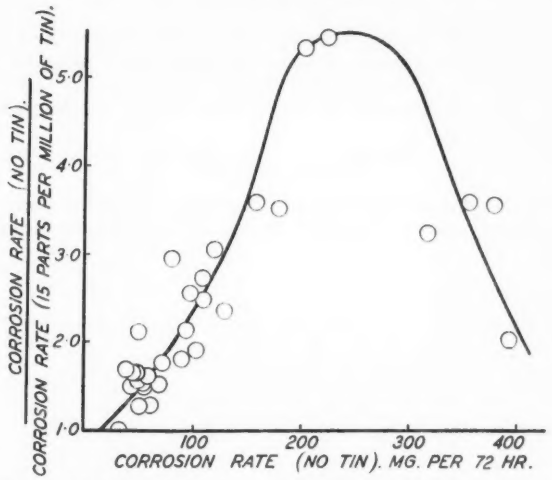


FIG. 4.—Influence of 15 parts per million Sn added as Sn^{++} on corrosion rate in 0·1*M* citric acid.

(corrosion without tin)/(corrosion with added tin) is seen to increase as the corrosion rate in the plain solution increases (except that in the case of the very rapidly corroded steels the ratio falls again).

The significance of the electrochemical results may now be considered. When a metal dissolves in acid with the evolution of hydrogen gas, certain points on the metal surface are especially active for the discharge of hydrogen ions by the cathodic process:

$$2H^+ + 2\epsilon \longrightarrow 2H \longrightarrow H_2.$$

NOTE ON TABLE II.

All the numbers given are means of triplicates. A rigid calculation of the standard deviation of the means would be rather laborious and seems unnecessary. But it may be stated qualitatively that the "probable error" (defined as 0·67449 × the standard deviation) of the mean corrosion rates as given is less than ± 4% in all cases (except for material No. 18, which was very unreproducible, and consequently of little significance). Also, the probable error of the corrosion potentials is about ± 2 mV.

It is thought that certain heterogeneities, grain-boundaries, or other discontinuities are the most active parts of the metal in this respect, but the exact location of such cathodic points does not at present concern us. At anodic points all over the metal, the reaction in the case of iron is the fundamental " corrosion " one :

$$Fe \longrightarrow Fe^{++} + 2\epsilon,$$

the metal here dissolving as ferrous ions. The rates of the cathodic and anodic processes must, of course, be equal, and equivalent to the total integrated current flowing between the cathodic and anodic points. This current will be determined by the working e.m.f. of the corrosion cell

$$\begin{array}{c|c|c} \text{Cathode} & & \text{Anode} \\ H_2 & H^+,\ Fe^{++} & Fe \end{array}$$

and its internal ohmic resistance. The term " cathode " includes all the cathodic points, " anode " indicating all the anodic points.

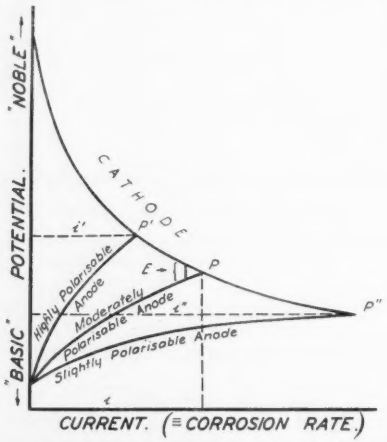


FIG. 5.—Polarisation of Cathode and Anode (Schematic).

Owing to polarisation of both the hydrogen cathode and the iron anode by the current passing, the e.m.f. of the cell sinks to a small value; but since the ohmic resistance through the electrolyte, for all the tiny " local elements " *in parallel*, must also be very small, a considerable corrosion current can flow.

The polarisation of the cathode and anode with current is represented schematically in Fig. 5. The cell will polarise, under conditions of low internal resistance, until its e.m.f. falls to the small value E, the final difference between the cathodic and anodic electrode potentials; in the limit, as E becomes very small, the

corrosion current tends to approach the value i, where the cathodic and anodic polarisation curves intersect, at the point P. Thus, if one plots the measured corrosion potential of the whole specimen against its corrosion rate, the latter being, of course, equivalent to the corrosion current, one obtains a close approximation to the point P.

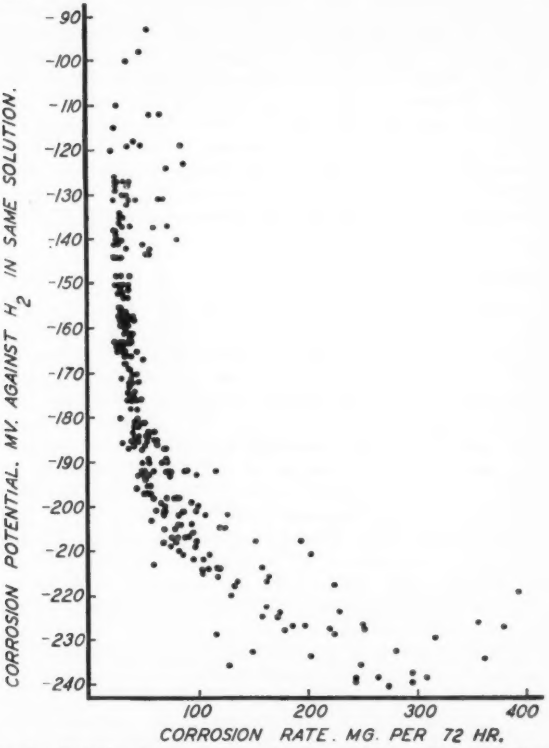


FIG. 6.—Relation between Corrosion Potential and Corrosion Rate.

Fig. 6 is a graph of all the corrosion rate and corrosion potential data of Table II., obtained from the thirty-six materials at pH 1·98, 3·64, and 4·98, with and without additions of sulphur and tin. The zero of the potential scale is the potential of the reversible hydrogen electrode in a solution of the same pH as the corroding medium. With some score of exceptions, all the 291 points lie remarkably close to a single curve, which has the form of a cathodic polarisation curve. In other words, the displacement of the cathodic

potential from its zero value (the reversible potential) is nearly the *same* function of the corrosion rate ($\equiv$ current) for *all* the materials under *all* the conditions studied. The conclusion can hardly be escaped that all the materials, even under the nine different conditions of corrosion, have *approximately* equivalent cathodes, and that their different rates of corrosion are therefore due to their widely differing anodes. For a material with a highly polarisable anode, the anodic polarisation curve will cut the fundamental cathodic curve at a point such as P' (Fig. 5), and the corrosion rate (equal to $i'F$, where F is the Faraday equivalent) will be relatively small. For a material with a much less polarisable anode, the anodic curve will cut the cathodic at P'', and the corrosion, $i''F$, will be relatively great. It will be convenient to consider first the alterations of corrosion rate caused by the change of pH, then the alterations caused by factors influencing the anodic process, and finally the alterations caused by the deviations from the "standard" cathodic process.

The Influence of p*H.*

The zero of the potential scale of Fig. 6 is the reversible potential of a hydrogen electrode in a solution of the same pH as that used in any particular test. In fact, the values of the corrosion potentials set forth in Table II. and plotted in Fig. 6 are the displacements from the reversible hydrogen potentials caused by the corrosion current, that is, they are cathodic overpotentials. But if the *normal* hydrogen potential is taken as zero, the reversible hydrogen potentials in solutions of pH 1·98, 3·64, and 4·89 are respectively $-0{\cdot}117$, $-0{\cdot}215$, and $-0{\cdot}289$ volt. On this scale, therefore, the points obtained from experiments in the three solutions will give three different curves, as shown schematically in Fig. 7; the coincidence of these curves when plotted as in Fig. 6 indicates that, under the experimental conditions used, overpotential is independent of pH,[1] while the reversible potential is, of course, a linear function of pH.

Now, if the anodic polarisation curve on the normal hydrogen scale for any one material is not affected by pH, it will cut the three curves of Fig. 7 at the points A, B, and C, illustrating the fact that an increase of pH results in a marked decrease in the corrosion rate. Actually, it is probable that an increase of pH somewhat lowers the anodic curve, but not nearly sufficiently to counterbalance the lowering of the cathodic curve on the normal hydrogen scale.

Factors Influencing the Anodic Process.

(*a*) *The Influence of Dissolved Sulphur.*—Reference to Table II. shows that the addition to the corroding medium of 15 parts per

[1] *Cf.* F. P. Bowden, *Transactions of the Faraday Society*, 1928, vol. 24, p. 473.

million of sulphur as sulphur dioxide invariably lowers the corrosion potential. This means that it diminishes the anodic polarisation. Sulphur dioxide, on reaching the corroding iron, is at once reduced to hydrogen sulphide, and since exactly similar effects are produced by this compound introduced as such, it may be safely assumed that it, or possibly the sulphide ion, is the effective agent. Clearly, then, any hydrogen sulphide produced by the dissolution of the sulphide contained in the steel itself, must have a like effect in diminishing the anodic polarisation and hence stimulating corrosion.

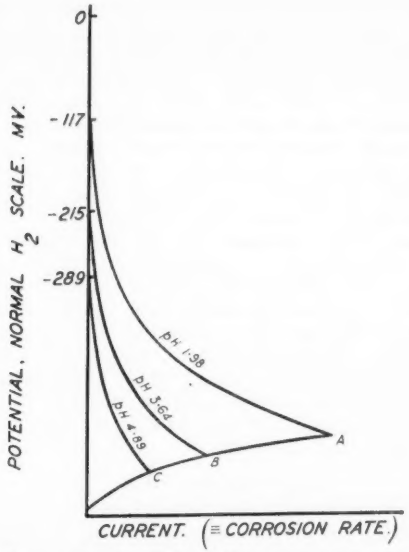


FIG. 7.—Influence of *p*H on Polarisation Curves and Corrosion Rate (Schematic).

This is confirmed by the fact already established (*see* Fig. 3) that the corrosion of the "slow" steels, presumably producing little hydrogen sulphide on their own, is greatly accelerated by the addition of 15 parts per million of sulphur; whereas that of the "fast" steels, already producing sufficient sulphide to bring their anodic polarisations, and hence their corroding potentials, down to the lower values necessary for rapid corrosion, is influenced relatively little by the further 15 parts per million.

In the less acid solutions, despite the lowering of the corrosion potential by dissolved sulphur, the corrosion rate is considerably less affected than at *p*H 1·98, being almost unchanged at *p*H 4·89.

Similarly, the divergences between the " fast " and " slow " steels become quite small at *p*H 4·89. Evidently the anodic stimulation is here offset by a cathodic inhibition; the nature of this is discussed later.

The actual physico-chemical mechanism of the action of dissolved sulphur on the anodic process is being further investigated, and will be discussed elsewhere. It may be suggested that the diminished anodic polarisation of iron brought about by hydrogen sulphide is due to its specific adsorption on the iron surface, which assists the actual anodic process of electron-transfer.

(*b*) *The Influence of Dissolved Tin.*—The effect of tin ions on the acid attack of steel has long been regarded as a mystery.[1] It is known that their retarding influence on the corrosion by citric acid cannot be due to the deposition of metallic tin on the steel, for tin is usually anodic to steel under such conditions;[2] moreover, the present experiments show that tin ions affect not the *cathodic*, but the *anodic* process, raising the corrosion potential (*see* Table II.) by increasing the anodic polarisation. It therefore appears likely that tin ions act by *removing* hydrogen sulphide from its sphere of action on the anodic process—which is precisely what would be expected, since neither stannous nor stannic sulphide is soluble in dilute acids, and, even if not precipitated, will be formed in the colloidal state. In confirmation of this simple view, it may be noted (Table II.) that the corrosion of the nearly sulphur-free iron, No. 33, is very little retarded by tin ions. Furthermore, the result illustrated by Fig. 4, that the " slow " and " very fast " steels are less influenced by tin ions than are the " fairly fast," is entirely consistent with the sulphide-removal hypothesis. It can be shown by considerations of solubility product that, if $[H_2S]$ is the hydrogen sulphide concentration, the ratio

$$\frac{[H_2S] \text{ without added } Sn^{++}}{[H_2S] \text{ in the presence of } Sn^{++}}$$

increases with rise of $[H_2S]$, passing through a maximum where $[H_2S] = \frac{2}{3}[Sn^{++}]$, $[Sn^{++}]$ being constant at 15 parts per million. It has been shown that the corrosion rate increases continuously with increase of $[H_2S]$; therefore the ratio

$$\frac{\text{Corrosion rate without added } Sn^{++}}{\text{Corrosion rate in the presence of 15 parts per million of } Sn^{++}}$$

should increase with an increase of the corrosion rate without added Sn^{++}, and pass through a maximum, which is exactly what occurs, as seen in Fig. 4.

Further direct evidence favouring the sulphide-removal hypothesis was obtained by special comparative experiments carried

[1] O. P. Watts, *Transactions of the Electrochemical Society*, 1935, vol. 67, p. 259.

[2] T. P. Hoar, *Transactions of the Faraday Society*, 1934, vol. 30, p. 472.

out with materials Nos. 11 and 17, corroding in 0·1*M* citric acid of *p*H 1·98 with small additions of cadmium, aluminium, chromium, manganese, zinc, and sodium ions, in amounts equivalent to 15 parts per million of stannous or stannic tin (it being doubtful in which valency the tin operates). Only metals which do not deposit on steel under these conditions could, of course, be used. The results, given in Table III., show clearly that cadmium, with an insoluble sulphide, raises the corrosion potential and retards corrosion almost as much as tin; zinc, whose sulphide is partially precipitated in citric acid, has a moderate retarding effect; while the other metals, having sulphides soluble in citric acid, have no appreciable action.

TABLE III.—*Effect of Small Amounts of Metal Ions on Corrosion and Corrosion Potential of Steels Nos.* 11 *and* 17 *in* 0·1M *Citric Acid at* 25° *C.*

Corrosion potentials in mV., referred to hydrogen in same acid as zero. For normal hydrogen scale, *add* −117 mV.

Metal Ion.	Steel No. 11. Metal Ion ≡ 15 parts per million of Sn^{++}.		Steel No. 17. Metal Ion ≡ 15 parts per million of Sn^{++++}.	
	Weight Loss in 72 hr. Mg.	Corroding Potential. mV.	Weight Loss in 72 hr. Mg.	Corroding Potential. mV.
Nil	141·6	− 225	210·3	− 217
Na^{+}	...	...	203·0	− 216
Mn^{++}	137·2	− 222	189·6	− 214
Al^{+++}	151·2	− 222	187·1	− 214
Cr^{+++}	100·3	− 206	206·6	− 216
Zn^{++}	75·5	− 205	157·4	− 212
Cd^{++}	70·9	− 194	61·3	− 174
Sn^{++} / Sn^{++++}	55·4	− 194	40·8	− 181

(c) *The Influence of Sulphur Content and Distribution in the Steel.*—From the foregoing results showing the influence of dissolved sulphur, it will be at once evident that, *other things being equal*, the steels higher in sulphur, furnishing a greater concentration of dissolved sulphur near the corroding surface, should corrode the more rapidly in acid solution. Reference to Tables I. and II. shows that there is a tendency for the higher sulphur steels to corrode the more rapidly, but that the effect is by no means general; thus, steels Nos. 19 and 20, though high in sulphur, are quite " slow " (in citric acid), whereas Nos. 2 and 4, though low in sulphur, are quite " fast." But these apparent anomalies do not take account of two other important and variable factors, namely, (1) the variation of sulphur content with depth in the steel (for obviously it is with the *surface layers* that the corrosion experiments are concerned), and (2) the copper content of the steel.

To determine the actual sulphur content in the surface layers of the steel, the apparatus shown in Fig. 8 was used. A specimen of the same size as that exposed in the corrosion tests (3·5 × 2·5 cm.) was dropped into the tube *T*, which contained approximately 8*N* hydrochloric acid kept at 95–100° C. in a water-bath. When the ground stopper was replaced, only some 2 c.c. of air remained in the tube and the capillary connecting it to the gas-burette. Sulphur-free rubber tubing was used for the joints, and the burette was fitted with a float to minimise dissolution of hydrogen sulphide. A volume of 20 c.c. of hydrogen, containing traces of hydrogen sulphide, was collected, this amount being equivalent to 50 mg. of iron dissolved. The collected gas was slowly passed from the burette through the lead-acetate paper *L* (prepared in a standard

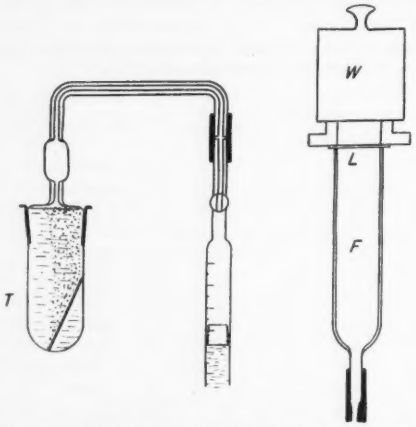


FIG. 8.—Apparatus for Estimation of Sulphur in Surface Layers of Steel.

manner), which was held on to the funnel *F* by means of a ground bakelite fitting and the kilogramme weight *W*. The stains produced were not quite uniform, but this did not interfere with their comparison with standards to within 10%. These were prepared from known amounts of sodium sulphide, from which the hydrogen sulphide was driven off by 8*N* hydrochloric acid and a current of pure hydrogen from spectroscopically pure zinc.

The sulphur content of the first 50 mg. layer of standard size specimens was determined for all the materials. The results, with the bulk sulphur analyses for comparison, are shown in Table IV.

It will be seen that the surface sulphur content of all the tinplate steels, Nos. 1–21 and 34–36, is only a fraction, one-tenth to one-half, of the bulk content, which is not surprising, since these materials were manufactured from rimming ingots. This explains the

TABLE IV.—*Sulphur Content in Surface Layers of Steel.*

Material. No.	Bulk Content. %.	First 50 mg. Layer. %.	Material. No.	Bulk Content. %.	First 50 mg. Layer. %.
1	0·017	0·0016	19	0·069	0·032
2	0·018	0·0024	20	0·071	0·015
3	0·030	0·0040	21	0·046	0·015
4	0·019	0·0026	22	0·021	0·017
5	0·042	0·0070	23	0·036	0·038
6	0·031	0·0050	24	0·049	0·060
7	0·043	0·0080	25	0·037	0·036
8	0·017	0·0034	26	0·035	0·042
9	0·017	0·0032	27	0·045	0·036
10	0·026	0·0032	28	0·039	0·036
11	0·014	0·0030	29	0·020	0·014
12	0·023	0·0075	30	0·020	0·016
13	0·029	0·0040	31	0·020	0·0050
14	0·056	0·013	32	Trace	0·0005
15	0·032	0·011	33	Trace	0·0005
16	0·062	0·028	34	0·030	0·018
17	0·058	0·024	35	0·035	0·012
18	0·035	0·0070	36	0·036	0·012

enhanced corrosion nearly always found at *p*H 1·98 near the edges of these steels; for at the edges the inner parts of the steel, higher in sulphur, are exposed, and produce a higher concentration of dissolved sulphide. The disappearance of the effect in the presence of 15 parts per million of added sulphur is due to the approximate equalisation of dissolved sulphur everywhere, the "slow" surface being accelerated up to the same rate as the "fast" edges. Again, the effect was not observed with steels Nos. 22–28, where the surface and bulk sulphur contents are approximately equal. The very "fast" steels Nos. 5, 7, 10, and 17 showed enhanced edge attack at first, but this was no longer true after 72 hr., when the general attack had reached the interior layers.

A complete study of the detailed correlation of depth, sulphur content, and corrosion rate would involve a large number of experiments on similar lines, and, for reasons of time, could not be undertaken in the present work. Even when the alteration of sulphur content with depth is taken into account, the corrosion rate is still seen to be dependent not only on the sulphur content, and the modifying effect of the copper content is dealt with in the next section. It is, however, quite clear that a low sulphur content in the surface layers will, other things being equal, give rise to a slow initial corrosion rate, except at places exposing inner layers richer in sulphur.

(*d*) *The Influence of Copper Content.*—In Table V. the ratio of the copper content to the sulphur content is compared with the corrosion rate in 0·1*M* citric acid, for each of thirty materials (the pure irons Nos. 32 and 33 and the tin-bearing steels Nos. 25 to 28

being omitted). The thirty materials are divided into two equal groups, the first comprising those materials with copper/sulphur ratios less than 1·38, the second those with ratios greater than 1·38. It will be seen that the materials of the group with the lower copper/sulphur ratios are in general much "faster" than those of the group with the higher copper/sulphur ratios, the average corrosion rates of the two groups under the experimental conditions used being 183·8 and 70·5 mg. per 72 hr. respectively. If the materials be divided into two groups of 19 and 11 in which the copper/sulphur ratios are respectively less than and greater than 2, the three "fastest" steels (Nos. 15, 17, and 19) of the "slow" group 2 of the table are transferred to the "fast" group 1, and the averages of the groups become 171·0 and 51·4 mg. per 72 hr. respectively.

TABLE V.—*Corrosion Rates of Two Groups of Steels in* 0·1M *Citric Acid.*

Group 1. $\frac{\text{Copper}}{\text{Sulphur}}$ Ratio < 1·38.			Group 2. $\frac{\text{Copper}}{\text{Sulphur}}$ Ratio > 1·38.		
Material. No.	$\frac{\text{Copper}}{\text{Sulphur}}$ Ratio.	Weight Loss in 72 hr. Mg.	Material. No.	$\frac{\text{Copper}}{\text{Sulphur}}$ Ratio.	Weight Loss in 72 hr. Mg.
5	0·17	355·7	17	1·41	222·7
24	0·22	392·2	15	1·59	118·9
7	0·26	378·4	13	1·65	58·0
10	0·39	316·4	19	1·65	92·5
3	0·47	97·5	22	2·10	68·0
6	0·50	108·0	14	2·24	50·1
4	0·58	177·8	12	2·26	51·2
8	0·77	90·1	36	2·30	48·9
2	0·78	157·2	35	2·31	45·2
9	0·82	103·1	23	2·53	71·0
1	0·88	61·0	34	2·67	46·6
11	1·00	128·9	29	2·95	51·1
16	1·30	108·9	30	2·95	42·4
18	1·34	201·5	31	2·95	52·9
20	1·35	80·5	21	3·42	38·3
Average.	0·72	183·8	Average.	2·33	70·5

The probability that the difference between the average corrosion rates of the two groups of Table V. is merely a chance effect may be shown by the methods of statistical analysis to be less than 0·001; that is, the odds that the result is "significant" are greater than 1000 to 1.

Since, however, many of the materials in group 2 of Table V. are not tinplate steels, it seemed desirable to test the effect of a high copper/sulphur ratio in more samples of tinplate material.

Nine more tinplates were taken at random from stock known to be fairly high in copper, and after de-tinning were subjected to the standard corrosion test in 0·1*M* citric acid. The results are given, with the copper/sulphur ratios, in Table VI.; they are entirely in harmony with the figures of Table V.

TABLE VI.—*Comparison of Corrosion Rate in* 0·1M *Citric Acid with Copper/Sulphur Ratio for Nine Supplementary Materials of Tinplate Type.*

Material.	Sulphur. %	Copper. %	$\frac{\text{Copper}}{\text{Sulphur}}$ Ratio.	Weight Loss in 72 hr. Mg.
A	0·068	0·101	1·48	132·5
B	0·038	0·055	1·55	113·2
C	0·057	0·091	1·60	105·0
D	0·058	0·096	1·66	42·5
E	0·056	0·102	1·82	79·4
F	0·066	0·124	1·88	124·2
G	0·066	0·135	2·05	62·2
H	0·037	0·077	2·08	61·8
I	0·052	0·170	3·27	43·3
Average.	...	...	1·93	84·9

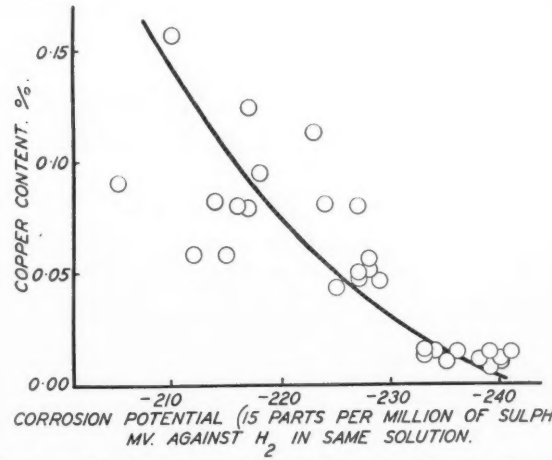


FIG. 9A.—Relation between Copper Content and Corrosion Potential in 0·1*M* citric acid + 15 parts per million of sulphur.

These considerations indicate that the presence of copper in the steel counteracts the accelerating effect of sulphur in the metal;

twice as much copper as sulphur seems to ensure that the steel corrodes relatively slowly under the experimental conditions. It is interesting to note that a very similar conclusion was reached by Buck [1] for the corrosion of steel in an industrial atmosphere.

The copper content also has an effect on the action of sulphur deliberately added to the corroding medium. Figs. 9A and 9B are graphs of the copper content plotted against (*a*) the corrosion potential, and (*b*) the corrosion rate, for the thirty materials in 0·1*M* citric acid with 15 parts per million of sulphur added as sulphur dioxide. Under these conditions of added sulphur, the sulphide

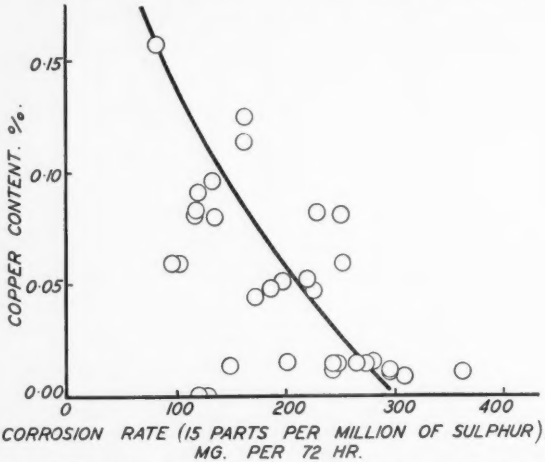


FIG. 9B.—Relation between Copper Content and Corrosion Rate in 0·1*M* citric acid + 15 parts per million of sulphur.

concentrations near the surfaces of all the materials are much more nearly similar than without added sulphur, for the sulphur dissolving from the metal has a proportionately less effect. The copper content is now seen to exert almost a controlling influence on the corrosion, the higher copper steels having less negative corrosion potentials and being the less attacked.

These results are in harmony with the generally held view that copper in steel retards acid attack; they extend it to a dilute solution of an organic acid, citric acid, and show that a copper content even well below 0·1% still has a considerable effect.[2] The mechanism of the action of copper has never been fully understood;

[1] D. M. Buck, *Proceedings of the American Society for Testing Materials*, 1919, vol. 19 (2), p. 224.

[2] *Cf.* P. Bardenheuer and G. Thanheiser, *Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung*, 1932, vol. 14, p. 1.

it has been ascribed to the formation of a film of copper or copper compound round the ferrite crystals [1]; to the "noble" properties of a solid solution of copper in iron [2]; and to the control of the harmful influence of sulphur.[3] This last explanation appears to be correct as far as it goes. It is well known by analysts that steels containing copper do not always evolve all their sulphur as hydrogen sulphide when dissolved in dilute sulphuric acid; moreover, the undissolved spongy residue, left when hydrogen evolution ceases, may contain most of the copper and some sulphur. The rise of corrosion potential with copper content, Fig. 9A, indicates that hydrogen sulphide is probably removed as insoluble copper sulphide; the very finely divided state of the copper left as the iron dissolves no doubt facilitates this action. It is also possible that in copper irons and steels low in manganese some of the sulphur actually exists as copper sulphide, insoluble in dilute acids; but in steels containing 0·3–0·5% of manganese, most of the sulphur is known to be present as acid-soluble manganese and ferrous sulphides, and any action of copper in "demobilising" sulphur must be a secondary one, as indicated above.

(*e*) *The Influence of the Tin Content.*—The tin-bearing steels Nos. 25 to 28, with a high surface sulphur content, are nevertheless quite "slow," and show at *p*H 1·98 a general decrease in corrosion with increasing tin content. This was to be expected, in view of the retarding action of tin ions in solution. It should be noted, however, that tin appears to be less effective than a similar amount of copper.

Factors Influencing the Cathodic Process.

(*a*) *The Influence of Heterogeneity in the Metal.*—The scatter of the points on the corrosion-velocity/corrosion-potential curve, Fig. 6, is far too great to be accounted for by experimental error. The materials which give points above and to the right of the mean curve clearly have more efficient cathodes than those giving points below and to the left. This is shown in more detail in Fig. 10, which is an enlarged graph of the part of Fig. 6 lying below − 180 mV., with the *logarithms* of the corrosion velocities as abscissæ. The points lie on and about a straight line, as would be expected from fundamental overpotential considerations,[4] provided that the cathodic reaction is solely one of hydrogen evolution. Above − 180 mV. the falling off of the curve from linearity indicates that oxygen depolarisation is becoming comparatively important, owing to the much smaller hydrogen evolution. For simplicity, the following

[1] E. A. and L. T. Richardson, *Transactions of the American Electrochemical Society*, 1920, vol. 38, p. 221.

[2] C. F. Burgess and J. Aston, *Industrial and Engineering Chemistry*, 1913, vol. 5, p. 458.

[3] D. M. Buck, *Transactions of the American Electrochemical Society*, 1921, vol. 39, p. 109.

[4] R. W. Gurney, *Proceedings of the Royal Society*, 1932, A., vol. 134, p. 137.

argument is confined to the part of the curve shown in Fig. 10, where the cathodic reaction is almost entirely that of hydrogen evolution.

The points marked as black circles in Fig. 10 refer to materials Nos. 5, 6, 7, 10, 12, 13, 14, 15, 16, 17, 20, and 21, which show particularly large amounts of massive cementite (*see* Figs. 1A and 1B) in the surface layers which are concerned in the corrosion. They may be compared with the points marked as plain circles, which refer to the otherwise similar materials Nos. 1, 2, 3, 4, 8, 9, 11, 18, 19,

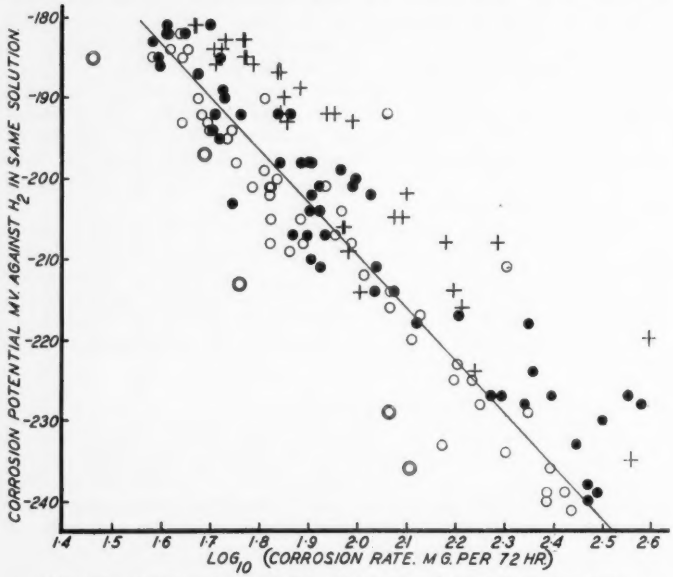


FIG. 10.—Relation between Corrosion Potential and Corrosion Rate (Detailed).

22, 34, 35, and 36, which contain much less cementite in the surface layers. (The points otherwise marked refer to materials different in other ways, and will be considered later.) It will be seen that materials containing much cementite tend to give points above and to the right of those referring to the more nearly homogeneous materials, indicating that the former have more efficient cathodes. The straight line has been drawn so as to divide the points under consideration into two groups of fifty-one each. The group above and to the right of the line contains thirty-eight black and thirteen plain circles; that below and to the left, fifteen black and thirty-six plain circles. The odds that this distribution occurs because of a

real cathodic difference between the materials referred to by black and those referred to by plain circles, rather than owing to a chance effect, may be shown to be at least 5×10^3 to 1. It thus seems reasonably certain that the presence of massive cementite tends to assist the cathodic process, and hence accelerate corrosion under these conditions.

It is pertinent to inquire whether other inclusions normally present in mild steel can act as especially efficient cathodic points in acid attack. To be cathodic, an inclusion must fulfil certain conditions. Thus, it must conduct electricity; this condition excludes silicates, &c. It must not be readily soluble in acids, nor must it be reducible to a readily soluble body; this excludes iron and manganese sulphides and oxides. Furthermore, a highly dispersed second phase, even if insoluble, will be exfoliated so readily by the dissolving ferrite that any cathodic action will be highly transient; thus pearlitic cementite cannot be expected to be as active as massive cementite. The only common inclusions not ruled out are massive cementite and iron phosphide, Fe_3P; the former has been shown to be cathodic, and phosphide, if and when present, may be expected to have a similar action. This may explain the accelerating effect of high phosphorus content, claimed by some authors.

It may be noted that the low points marked as double circles, which indicate inefficient cathodes, refer to the pure irons Nos. 32 and 33, which are the most nearly homogeneous, and have the largest grain-size, of any of the materials used.

(*b*) *Other Apparent Deviations from the Standard Cathodic Process.*—The explanation of the high points marked as crosses (Fig. 10), which represent materials Nos. 23–29, is less certain. These materials had smaller grain-size than the tinplate steel-base materials just considered (Fig. 1), and a (sulphur in surface)/(sulphur in bulk) ratio of approximately 1 (Table IV.), much higher than that of the tinplate steels made from rimming ingots. It can thus be argued, (1) that these points represent a true increase of cathodic efficiency, due perhaps to the greater total length of grain-boundary giving more cathodic points; or (2) that the high surface sulphur content has produced faster initial corrosion than in the case of the rimming steels, and hence the 72-hr. corrosion loss is comparatively greater, for the same final corrosion potential—which would shift the points towards the right of Fig. 10. Further work is required to clear up this point, but it may be expected that the complete explanation is a combination of effects (1) and (2), with (2) predominating.

(*c*) *The Influence of Dissolved Oxygen.*—It has been remarked that at corrosion potentials more noble than − 180 mV. (referred to the hydrogen potential in the same solution), depolarisation by oxygen becomes comparatively important, owing to the diminishing hydrogen evolution. An increase of *p*H, which makes the corrosion

potential less negative to hydrogen (*see* Table II.), thus results in an increased tendency for depolarisation by oxygen to predominate; in some cases, at high *p*H, such depolarisation may constitute almost the entire cathodic reaction.

The points at high corrosion potentials which lie well to the right of the corrosion-velocity/corrosion-potential curve, Fig. 6, may now be considered. They mainly refer to experiments at *p*H 3·64 and 4·89 with materials Nos. 31–36. It was thought that the exceptionally efficient cathodic process which they represent must be due to exceptional capacity for the oxygen depolarisation process. This was confirmed by experiments carried out with materials Nos. 31 and 36 in rigorously air-free nitrogen, all other conditions being the same as in the main experiments. The results, with the air-present results for comparison, are shown in Table VII. The exceptionally high corrosion at *p*H 3·64 and 4·89 does not occur in the absence of air; the corrosion at *p*H 1·98, though considerably reduced in the absence of air, is relatively less affected than that at the higher *p*H values.

TABLE VII.—*Corrosion of Materials Nos.* 31 *and* 36 *in Presence and Absence of Air.*

Material. No.	Condition.	Weight Loss in 72 hr., Mg., at —		
		*p*H 1·98.	*p*H 3·64.	*p*H 4·89.
31	Air present.	52·9	78·7	85·8
	Air absent.	15·7	5·8	4·0
36	Air present.	48·9	79·9	83·2
	Air absent.	33·6	29·1	24·5

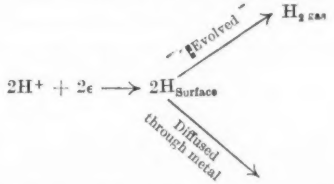
This especially high capacity for oxygen depolarisation in the less acid solutions was shown only by materials Nos. 13 and 31–36, and to some degree by No. 21 (Table II.). It may be noted that these are all "slow" materials (at *p*H 1·98), producing little dissolved sulphur. The effect of sulphur on the cathodic process is discussed in the next section.

(*d*) *The Influence of Dissolved Sulphur.*—It has already been pointed out that the addition of dissolved sulphur to the corroding media at *p*H 4·89, although lowering the corrosion potentials of all the materials in such solutions, causes no increase in the corrosion rates. Therefore, besides anodic stimulation, there is cathodic inhibition; clearly it is the oxygen depolarisation process, predominant at *p*H 4·89, which is inhibited. It may be suggested that hydrogen sulphide becomes preferentially adsorbed at centres otherwise active for the oxygen depolarisation.

The exceptional oxygen depolarisation discussed in the preceding section was never found when the solution contained added sulphur

(Table II.). Indeed, it seems to occur only when the dissolved sulphur is kept minimal, for even in initially sulphur-free solutions it was shown only by the pure irons Nos. 32 and 33, and by materials Nos. 13, 21, 30, 31, 34, 35, and 36, with high copper/sulphur ratios. Evidently the *normal* cathodic process at high *p*H is oxygen depolarisation *somewhat inhibited* by dissolved sulphur derived from the steel. Herein lies the reason for the corrosion-rate variations found among the steels at *p*H 4·89 being much smaller than those found in the more acid solutions. Those materials furnishing the most dissolved sulphur, though having the most efficient anodes, have at *p*H 4·89 the least efficient cathodes; the effects counterbalance each other. In the absence of air, however, the (very small) corrosion rates may be expected to vary greatly, just as at *p*H 1·98, for the hydrogen-evolution cathodic process is not greatly affected by sulphur.

The main hydrogen-evolution cathodic reaction appears, however, to be *slightly* inhibited by sulphur, for there is some tendency for points referring to sulphur-containing solutions to lie below and to the left of the line in Fig. 10, as may be seen by reference to that diagram and to Table II. The complete cathodic process may be written :



It seems probable that sulphur retards the process $2H_{surface} \longrightarrow H_{2\ gas}$, but does not affect the other processes. Thus, only a slight interference with the total cathodic process is to be expected, for with sulphur present the surface concentration of hydrogen atoms builds up so as to discount the retardation of $2H \longrightarrow H_2$ due to the sulphur. This enhanced surface concentration gives rise to increased diffusion of atomic hydrogen through the metal, a phenomenon observed by Morris [1] and Bablik [2]; in the present work, the wax covering of the top parts of specimens in sulphur-containing solutions was sometimes blown off by the excessive diffused hydrogen.

General Conclusions.

The specific conclusions resulting from these experiments could not have been reached except by means of the electrochemical measurements in conjunction with corrosion measurements. The

[1] T. N. Morris, *Journal of the Society of Chemical Industry*, 1935, vol. 54, p. 7T.

[2] H. Bablik, *Korrosion und Metallschutz*, 1935, vol. 11, p. 169.

value of the electrochemical technique lies, in this instance, in the power it gives for separating the many factors at work into two main classes, *viz.*, anodic and cathodic factors. Thus, the effects of sulphur (anodic) and of cementite (cathodic) could not have been disentangled without a knowledge of the mechanism involved. In particular, the effect of sulphur as an *anodic* stimulant is clearly indicated. Previous workers [1] have attributed the accelerating effect of sulphur to the deposition of cathodic ferrous sulphide patches on the iron—an improbable explanation (in view of the known solubility of ferrous sulphide in acids) which the present work shows to be definitely incorrect. Again, the inhibiting effect of tin ions is shown to be *anodic* in mechanism. It has been previously suggested [2] that tin is a cathodic inhibitor because it raises the cathodic overpotential of iron when current is applied. But under such conditions tin can be deposited on the iron cathode, whereas the potential of a corroding iron or steel specimen without an applied current is, in citric acid, too noble for such deposition to be possible; results obtained with applied current are not necessarily comparable with those obtained under corroding conditions.

All the phenomena observed in the present work are explicable as being due to sulphur, copper, tin, and to structural variations. Nevertheless, it is quite possible that other elements present in mild steel, such as phosphorus, arsenic, and oxygen, have appreciable effects. Further work should be carried out, in the light of the factors already established, to determine these.

Significance of the Results in Regard to Tinplate.—The particular case of the corrosion of tinplate presents special features. The steel-base is inevitably exposed at defects in the tin coating, which are at present inherent in the processes of manufacture and fabrication. Nevertheless, tinplate possesses several accidentally favourable properties so far as the corrosion of the tinplate container by fruit acids is concerned : (*a*) The steel-base is frequently rimming steel; (*b*) tin in contact with steel may afford cathodic protection to the steel, as the tin usually becomes anodic; (*c*) tin ions in solution inhibit the corrosion of steel. It has been shown by one of the authors [3] that for a *slowly corroding* steel (No. 22 of this research), steel in the tin-iron couple in citric acid becomes cathodic almost immediately; the corrosion potential of the steel is 30–50 mV. more noble than that of tin, both metals being free from oxide film. On the other hand, a rapidly corroding steel may well have a corrosion potential at least 50 mV. less noble than that of a slowly corroding steel (*see* Table II.), and when coupled with tin it may be expected to become anodic. Tin, being afforded cathodic pro-

[1] W. A. Karnitzkij and N. A. Golubew, *Korrosion und Metallschutz*, 1934, vol. 10, p. 190.

[2] E. F. Kohman and N. H. Sandborn, *Industrial and Engineering Chemistry*, 1928, vol. 20, p. 1373.

[3] T. P. Hoar, *Transactions of the Faraday Society*, 1934, vol. 30, p. 472.

tection, will corrode especially slowly; thus tin ions in solution, which will eventually raise the steel potential enough to make the steel cathodic, are slow in forming. The steel will therefore undergo a long initial period of anodic attack. Preliminary experiments have shown this to be the case; in citric acid, tin-steel couples made of "slow" steels become steel-cathodic in a few seconds, whereas those made of "fast" steels may take days to do so, the steel suffering severe attack meanwhile. There thus seems to be ample justification for the rejection of "fast" steels as steel-base for tinplate, on account of their low corrosion potentials, as well as their high corrosion rates.

Practical Implications.

The results of this work and the general theory derived from it suggest that steel which may come into contact with dilute organic acids such as citric acid should preferably, from the corrosion point of view, possess the following features:

(1) A low sulphur content, especially in the surface layers; rimming steels would appear to offer some advantage.
(2) A copper content not less than twice that of sulphur.
(3) Freedom from massive cementite.

Tinplate is extensively used for containers for acid food-stuffs. It would appear very desirable that the steel-base should be of the slowly-corroding type, and it may be suggested that this can be simply achieved by the use of rimming steel having a copper content not less than twice as great as the sulphur content.

Acknowledgments.

This work forms part of a programme being undertaken by the International Tin Research and Development Council. We are grateful to the Director of Research, Mr. D. J. Macnaughtan, for his constant helpful interest in the work and for permission to publish. Facilities for the metallographic part of the work were kindly provided for one of us (D. H.) by Professor J. H. Andrew at Sheffield; the corrosion work was carried out by the other (T. P. H.) at Cambridge through the kindness of Professor R. H. Hutton and Dr. U. R. Evans. Finally, our best thanks are due to Mr. G. E. T. Eyles for much careful assistance in the practical work.

DISCUSSION.

Mr. D. J. MACNAUGHTAN (London) said he welcomed the opportunity of opening the discussion, and wished to emphasise the importance of the work described in the paper to those engaged on corrosion research, while, if the conclusions were substantiated, its importance to those engaged on the manufacture of tinplate was also obvious. The outlet for tinplate in the canning industry was so great that any method for the improvement of tinplate with respect to the troubles that arose in that industry were clearly of very great advantage to tinplate manufacturers.

One of the chief troubles which arose in the canning industry was the corrosion which occurred with a considerable variety of food-stuffs and produced hydrogen in the can, causing it to swell up at the ends and unfortunately making it unsaleable, although the contents were not necessarily bad. In the aggregate this caused a considerable loss throughout the industry, and it not only affected existing products, but tended to retard the development of the canning of other products. Naturally much work had been done with a view to minimising the trouble, and important advances had been made.

The nature of the tin coating had been discussed a good deal, and was referred to in the paper by Hothersall and Prytherch [1]; but it had been recognised for a considerable time that, no matter what was done with regard to the tin coating, there was considerable evidence that the steel itself played an important part. In the United States of America a number of years ago a considerable amount of work was carried out on the effects of variation in the composition and quality of the steel base. The conclusions were, however, very indefinite. He believed that the chief element in the steel which was suspect was phosphorus. During that period and subsequently, however, contradictory evidence made the whole question of the influence of any particular element in the steel base a very open one, although there was clear indication that the nature of the steel was coming into play.

It was very fortunate that, with the growth of the canning industry in Great Britain, a policy was adopted of working along fundamental lines. Realising the complexity of the problem, work at Cambridge was started to deal with the fundamentals of the question. He was pleased to see that Mr. Morris and Dr. Bryan were present that morning, because there was not the slightest doubt that they had really made outstanding advances in clarifying the position. In the first place, they had definitely established in their work, using a type of medium similar to that which gave trouble with a whole range of canned fruits, that some steels were " fast " steels and some were " slow." They also found,

[1] This Journal, p. 205 P.

in other lines of investigation, that certain sulphur compounds when added to the corrosive media speeded up the rate of attack, and also that a minute concentration of tin ions in the solution retarded the attack. He thought the authors of the present paper would agree that those were clues of great value to themselves, and that that work would always be regarded as basic work of the greatest importance.

With regard to the particular work described in the present paper, he thought it was of special value in at least providing something like a rational explanation of why some steels were fast and others were slow in media of the type which did produce trouble in industry, and in showing the connection between this and the opposing influences of sulphur and of tin, and in raising an entirely new issue of great interest, that of the influence of copper. Dr. Hoar found the key in the relation between corrosion potential and corrosion rate, established by about 270 observations with more than thirty different steels, studied under nine different conditions of corrosion. The deductions made from this relationship was one of the most delightful pieces of reasoning in the whole literature of corrosion. It would appear to clear up much of the confusion arising from the contradictory evidence which had been available as to the influence of the various elements in the steel in relation to the basic corrosion problem involved, which was the anodic dissolution of iron and the cathodic discharge of hydrogen.

It was a matter of definite basic importance to know that sulphur stimulated the anodic attack and that massive cementite was the main factor influencing the cathodic reaction, and it was of great practical significance to appreciate the restraining influence of tin and the greater restraining influence of copper, and to have it shown that their rôle consisted in removing the sulphur as an insoluble sulphide.

All kinds of difficulties might arise with regard to some aspects of the interpretation of the results, but the broad picture which had now been obtained was not merely intellectually satisfying, but definitely opened up lines of improvement in the steel base for can making, and was a strong vindication of the method employed of obtaining material from the industry and, in view of the large number of variables, studying the whole matter statistically.

He did not think that the work would have materialised in the way that it had but for the invaluable clues provided by Morris and Bryan. Further, it could not have been carried through with the data available without a thorough understanding of the electrochemical phenomena involved. Dr. Hoar's determination to get down to fundamentals in this respect, and the associated work of Mr. Havenhand in regard to the structure of the steels and the distribution of cementite was a useful example of collaboration between the Chemical Laboratory of the University of Cambridge and the Metallurgical Laboratory of the University of Sheffield.

Principal C. A. Edwards, F.R.S. (Swansea), said he could not be accused of unduly rushing into discussions on corrosion problems; usually he felt quite satisfied to leave such subjects to those who had made a special study of them. On the present occasion, however, he felt that it was important that some word of warning should be given, because the conclusions drawn in the present paper were very important *if*, as Mr. Macnaughtan said, they were correct. Unfortunately, however, the conclusions were based on quite inconclusive evidence, and the materials which the authors had used, from the point of view that they had in mind, were utterly useless. He was sorry to have to speak in that way; he would have preferred to sit down and listen to what others had to say.

A few years ago he was induced to take up, to a limited extent, the study of the corrosion of tinplates, but, knowing as he did something about the heterogeneous character of steel ingots, and recognising that corrosion was essentially a surface phenomenon, and that tinplate manufacture represented the conversion of the ingot into as large a surface in relation to mass as it was possible to accomplish, he felt that certain very definite precautions must be taken in the study of the problem.

If we were to understand the influence of any particular element present in steel, and its effect on the corrodibility of tinplate in particular, it was necessary, he thought, that the following important points should be borne in mind. First, he thought anyone accustomed to scientific investigations would agree that all elements other than the one which was under consideration should be kept as constant as possible. Secondly, every effort should be made in cases of this kind to minimise the degree of segregation of that particular element, especially during the freezing of the ingot. Thirdly, those who knew something about the problem under discussion would agree that the degree of hot-rolling in the process of manufacturing the tinplate, when studying this aspect of the problem, should be minimised, if only to avoid excessive scaling of the steel and absorption of oxygen by the metal itself during the rolling, because the authors themselves suggested that the oxygen had a very important influence. Fourthly, it was also necessary that the material which was to be used should have as smooth a finished surface as possible, and the best means of bringing that about was by cold-rolling operations. The last point of some importance which he would mention was that the experimental specimens should be annealed at known temperatures and under carefully standardised conditions.

With those points in mind, when the investigations were started at Swansea the very last thing they wanted to do—though it might sound rather strange to the authors—was to take bars from commercial ingots. That was in no way a reflection on the commercial producers of tinplate, but was merely intended to emphasise

the importance of the scientific method of attack when dealing with materials such as dead mild steel in the form of such thin sheets as were used for tinplate making. Unfortunately, the authors seemed to have overlooked all those points. He was not surprised that they were not acquainted with them all, but he was surprised that they had not been warned by some of those with whom they had been in contact against some of the pitfalls to which he had referred; and, if they had been warned, he could not understand why they had not taken the opportunity of seeking advice, and possibly help, from those who knew something about the subject.

To illustrate how easy it was for results of the kind in question to be very seriously affected by comparatively small variations in the treatment of the specimens, he would like to refer to something of which some of his audience had already heard, and about which they might have warned the authors. In the early stages of the work to which he referred, he and his co-workers found that if they took five small experimental samples and wrapped them up for annealing purposes in a case of thin sheet steel, two of those samples would give very erratic results, whereas three of them would give concordant results. If, however, the wrapping material was of the same composition as the samples which were to be tested, then all five samples gave good results. They believed, though they would not like dogmatically to assert, that the difference in that connection was entirely due to the passage of phosphorus from the material that they used in the early stages for wrapping purposes to the two surfaces which were in contact with the material in which they were wrapped. That showed how comparatively small variations in the conditions of annealing could affect the values of the corrosion results obtained.

The authors, in their general conclusions, suggested that all the phenomena which they had observed were explicable as being due to sulphur, copper, tin, and structural variations, but how they could suggest that that was the case when they immediately followed that observation by the statement, "Nevertheless, it is quite possible that other elements present in mild steel, such as phosphorus, arsenic, and oxygen, have appreciable effects" he did not understand. Since they had not endeavoured to control the three elements to which they referred, how could they suggest that the results they obtained were explicable as being due to copper and sulphur?

With regard to the authors' figures relating to the material used, they were trying to work out the effect of sulphur, but the phosphorus varied from 0·005 to 0·071%, a variation as wide as, if not a wider than, that of the element they were studying. That would be quite satisfactory, of course, if the phosphorus had no influence, but the evidence (obtained at Swansea) showed that with both sulphuric acid and citric acid solutions, variations of

phosphorus of that magnitude had an effect which was much greater than corresponding variations of sulphur. He was not going to suggest that the authors must conclude that by plotting their data of corrodibility against phosphorus content they ought to get a linear relationship; the other variables were far too great for that to be revealed.

He and his co-workers had carried out a fairly extensive series of investigations by intentionally varying the sulphur content, keeping all the other elements constant. The experimental samples were made in the laboratory by a method which he thought was beyond reproach for experiments of the kind in question. By varying the sulphur content from, say, below 0·04 up to 0·18% it was scarcely possible to observe any difference in the corrodibility of the samples when those samples were examined in the annealed condition, but if the specimens were examined in the cold-rolled state the influence of sulphur was considerable. In other words, the high sulphur content in the cold-rolled state gave a corrodibility of something like six or seven times that in the annealed state; but of course tinplates were never used in the cold-rolled state.

With regard to copper, a series of steels had been made containing varying copper contents, and they had examined them in the same way, and, when the other elements were kept constant, the effect of copper upon the rate of attack in acid solutions—what he was saying had nothing to do with atmospheric corrosion—was that by varying the copper from almost zero up to 0·5% they could find no effect due to that element at ordinary atmospheric temperatures, but they did find an effect if the temperature was raised to, say, 75° C. Food contained in cans, however, was, of course, usually kept at ordinary temperatures.

He would like to draw the attention of the authors to another element which they seemed to have overlooked, for although they referred to it they had not examined it—oxygen. He had not been able, of course, to estimate the oxygen content in the steels which he had examined, but those who knew what had been done in Swansea with regard to the making of synthetically prepared steel, introducing oxygen, and removing what was not wanted by means of aluminium, would, he thought, agree that they could produce ingots of progressively increasing contents of oxygen, and, while they did not know the amount of oxygen by chemical analysis, they had varied it in steps which were quite clearly defined. Working in this way they found that the influence of oxygen was very pronounced. It was much greater than that of sulphur, but not as great as that of phosphorus. For example, if, *while keeping the other elements constant*, the phosphorus content of a steel were raised from, say, 0·02% or less to 0·1%, the corrodibility in weak acid solutions such as the authors had used was increased by something like ten times.

He would like to make it perfectly clear that the observations which he had made were not intended as an attack in any sense of the term. All that he wanted to do was to urge those who wished to study the influence of any feature of tinplate making, or the behaviour of the product, not to mislead themselves, and certainly not to mislead users of tinplate, but to seek, through every possible avenue, the advice of those who were associated with the trade, and the advice of those who really would most willingly offer their assistance. He hoped that Dr. Hoar, whom he had not previously had the pleasure of meeting, would not regard his remarks as a personal attack. He had nothing but praise for the purely theoretical means of treating the subject; all he regretted was that the authors had not had the good fortune to have carefully selected material with which to work.

Dr. W. H. Hatfield, F.R.S. (Vice-President, Sheffield), said he had read the paper with the greatest interest. While, after a preliminary glance through it, one was impressed with the deductions arrived at, when the matter was carefully analysed he must confess that there was a very good case for the line which Principal Edwards had taken that morning. All those who were working on steel metallurgy were very well aware of the vast amount of physical and chemical data relative to steel derived from experiments over the last sixty or seventy years by very capable physicists and chemists. Curiously, the bulk of those data were having to be redetermined. It was not enough for the great Professor Barrett to get hold of a piece of steel and determine the physical properties, in comparative ignorance of what the material really consisted of; it was necessary that he should know all about that piece of steel—its history and everything about it—before physical determinations of any value could be put on record. The same thing applied in the present case.

He would like to ask the authors how they came across the specimens which they examined. Did they obtain those specimens as a result of assistance from men who really had a great interest in the work that they were doing, from the metallurgical point of view? He thought the answer was that the specimens were not properly selected, as Principal Edwards said. He would remind investigators that there was an Ingot Committee of the Institute and a Corrosion Committee of the Institute, and when investigations of the kind under discussion were undertaken, those Committees would be only too glad to see that adequate and suitable materials were placed in the hands of such investigators, without any cost to them. He was sure Sir William Larke would support him when he said that the Joint Committees of the Institute and the Federation would be very glad to see that adequate materials of a universally approved type were placed at the disposal of any investigators who were working on the applications of steel.

The steel under the tin, whatever the minor differences which might be disclosed by investigations of the kind in question, was a very readily corrodible material, and was simply a carrier of the tin. For a satisfactory solution of the problem on which Mr. Macnaughtan and his investigators were engaged it should be looked at from that point of view. No doubt the steel producer would be very glad to do all that he could to come within a technique which was regarded as best, but, after all, it was the facility and success with which the tin was attached to the steel which mattered. He was inclined to think that the actual process itself, whereby the tin was put on, was far more important than the nature of the underlying steel.

Reverting to the original point, he would like the authors to say how they came by their specimens, and to be good enough to let the Corrosion Committee have a few of those specimens for examination. The Committee would be very glad to comment on them. He hoped the authors would take note of the fact that simply to obtain samples of steel in the way that they had done, and to rub them with a piece of emery paper, removing " about 0·005 in."—an unscientific expression—was not good enough for critical corrosion tests. A quantitative investigation based on those lines of attack would not do at all.

He therefore joined with Principal Edwards in his very definite objections to the findings of the paper, owing to the nature of the material employed for the investigation and the manner of preparation of the samples; and he would end by offering to Mr. Macnaughtan and his investigators the full resources in material of the most suitable types which were available through the Institute and the Federation for any further investigations.

Mr. D. J. MACNAUGHTAN asked leave to intervene in the discussion again in order to comment on what had been said. With regard to Dr. Hatfield's point about the tin coating on the steel, that was being dealt with in a subsequent paper; but it was a conviction which had been growing over a long period of time, and which was emphasised by Principal Edwards' remarks with regard to the phosphorus content of the steel, that the steel did come into the picture. If the work on the steel was done in the way suggested by Principal Edwards, by a series of additions to ingots, it would have to go on for a great length of time. Thus, if one added increasing amounts of copper to pure iron, one sent up the corrosion, but if sulphur were present and the copper was added the copper decreased it. The justification of the investigation reported in the present paper was that materials in actual supply were used to get down to the actual mechanism that caused some steels to be " fast " and others to be " slow."

Mr. J. H. WHITELEY (Consett) said that he considered the authors had made a very skilful attempt to unravel an extremely

difficult and complicated problem. The curves they had given indicated that they had managed to reduce to a fair degree of order results which at first sight seemed almost chaotic. There were, however, several points in the paper to which he would like to refer. In the first place, it would be of interest to know whether the electrode potentials remained constant throughout the period of the tests. Apparently only one reading had been taken at the end of each experiment, as no reference was made to potentials obtaining during the 72-hr. periods. This was, he thought, of importance, since the corrosion potential had been used as one of the co-ordinates in several of the graphs.

Next, they were told that the steels used were of the rimming type. Now such steels had very definite and well-known characteristics, which were easily discernible in the finished products, even when in sheet form, unless they happened to have been rolled from the very bottom of the ingot. Except, perhaps, in Nos. 10, 35, and 36, these characteristics were missing. There was no indication of the type of segregation common to such steels, and he was of the opinion that they had been rolled from either effervescing or balanced ingots. Again, in Fig. 10, it was stated that the black circles referred to materials which showed particularly large amounts of massive cementite in the surface layers, and the plain circles to similar materials which contained much less carbide at the surface. Here also, on examining the illustrations, this was by no means apparent. For example, the quantity of surface cementite as revealed by sodium picrate in Figs. 8 and 9 (plain circles) was much the same as that seen in Figs. 5, 6, 7, and 10 (black circles). Moreover, samples Nos. 1 to 11 and 34 to 36 had all been annealed, and such treatment, with low-carbon steels of this kind, always caused the carbide to assume the massive form. Since the carbon contents were for the most part between 0·03 and 0·06% and the steels seemed to be otherwise very similar in character, it would be expected that they all had about equal amounts of surface carbide, and there was no apparent reason why some of these samples should have been included in the plain-circle group. Altogether, the evidence advanced that massive cementite tended to accelerate corrosion under the conditions of the tests could not be regarded as convincing.

Finally, he wished to comment on the results given in Table II. When the figures obtained with plain solutions at *p*H values of 3·64 and 4·89 were compared, it was seen that steels Nos. 31 to 36 showed an increased loss in weight with reduction in acid strength, while, in other cases, the retardation of attack was very irregular. For example, although samples Nos. 1 to 12 were very similar as regards their copper and tin contents, yet in the case of Nos. 1, 8, and 12 there was a difference in the loss of weight figures for *p*H 3·64 and *p*H 4·89 of less than 0·006 g., and in the case of Nos. 5, 7, and 10 of over 0·04 g. These variations the

authors set down to exceptional capacity for the oxygen depolarisation process, and then proceeded to demonstrate the effect of the absence of oxygen on steels Nos. 31 and 36 (Table VII.). He would suggest that the explanation would have been better supported if two steels which had shown a marked diminution in loss, say Nos. 5 and 7, had also been examined in this way for comparison.

He thought the authors had overshot the mark in dealing with the effect of sulphur. Take, for example, a "slow" steel, No. 1, and a "fast" steel, No. 5. From the data given in Table II. the maximum amount of sulphur which could possibly be present in the solution of *p*H 1·98 at the end of three days was approximately 0·005 part per million in the first case, and 0·125 part per million in the second. These figures were calculated on the sulphur contents of the surface layers. If the bulk contents were used they became 0·05 and 0·75 part, respectively. It seemed reasonable to average these figures, which then gave the maximum quantities for the two steels as 0·025 and 0·44 part per million. As a matter of fact, the figures would really be much less on the average because the sulphur was gradually passing into solution throughout the period of the tests. Yet, in order to test the effect of sulphur, the authors had added 15 parts per million to the solution. Since sulphides were rapidly attacked by citric acid, there could be little doubt that the bulk of the evolved H_2S would quickly diffuse into the liquid, and it therefore seemed to the speaker that it would have been more satisfactory if, say 0·25, or even less, part per million, instead of 15 parts, had been added.

CORRESPONDENCE.

Dr. J. C. HUDSON (Birmingham) wrote that he had attended the Meeting with the intention of congratulating the authors on their paper and that, having heard the discussion, he still wished to do so. They had conducted over 1000 quantitative experiments under well-controlled conditions and, whether time showed the conclusions they had deduced from their results to be right or wrong, their experimental data would remain as a valuable basis for checking future results obtained by themselves and other workers. On the other hand, on general scientific grounds, he (Dr. Hudson) agreed with the arguments advanced by Principal Edwards and Dr. Hatfield—which might perhaps be summarised by the statement that it was fundamentally desirable that work such as that of the authors should be carried out on materials of known origin and that great care should be exercised in applying the results for practical purposes, such as the tinplate industry. In view of Dr. Hatfield's offer to ensure an adequate supply of materials to the authors for their future work, no further difficulty should

arise in this respect, and the discussion would thus have served a very useful purpose by furthering that contact between the fundamental research worker and those engaged in practical production which was essential for the promotion of progress within the industry.

As regards the paper itself, it might be of value if he were to expand the authors' arguments in one or two directions, in the light of important results obtained in Germany. He referred in the first instance to the work of P. Bardenheuer and G. Thanheiser [1] on the effect of copper on the rate of dissolution of mild steel in dilute acids, the results of which were adequately summarised in their own words :

" It is incorrect to speak in general terms of a protective action of a copper addition to iron against acid attack. The addition of copper diminishes to a high degree the rate of solution of steels that are readily soluble as a result of their phosphorus and sulphur contents. The attack of acids on specimens which, as a result of their purity, show initially a small solution velocity is scarcely diminished by the addition of copper, and, indeed, is increased in isolated cases. These statements hold true for hydrochloric, sulphuric, and citric acids, but not for nitric acid, in which the rate of solution is independent of the copper content of the specimens."

Thus, Bardenheuer and Thanheiser observed that the rate of dissolution in dilute acids was much lower for steels with low phosphorus and sulphur contents than for those containing appreciable amounts of either or both of these impurities; the addition of copper to the steel had the effect of bringing the losses in weight of the various series of specimens to the same order of magnitude, irrespective of the basis composition of the material, since copper exerted a very marked protective effect in the case of materials with a high intrinsic rate of solution, but almost none in the case of those with a low rate. The results of these German workers thus supported the views of the present authors that the addition of copper to steel had a beneficial effect on its corrosion resistance if it contained appreciable quantities of sulphur, but they also agreed with the observations of Principal Edwards that phosphorus played a very important part in determining corrosion.

As a matter of interest, he (Dr. Hudson) had used the authors' data to correlate the copper/phosphorus ratio of the steels with the observed corrosion, as they had already done for the copper/sulphur ratio in Table V. of their paper. The results of his correlation were shown in Fig. A. It would be seen at once that for losses in weight between 58 and 400 mg., the curve connecting the corrosion rate with the copper/phosphorus ratio varied in exactly the same way as that connecting the corrosion with the copper/sulphur

[1] *Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung*, 1932, vol. 14, p. 1.

ratio. There was no exception to this statement over the whole of this range of loss in weight, which included twenty of the twenty-nine steels for which correlation was possible in both cases. The remaining nine steels, with losses in weight below 58 mg., fell in a comparatively small field within which differences in the individual corrosion rates were small, and often less than the probable experimental error of $\pm 4\%$, given by the authors; in addition, in the case of three of the materials (the ingot irons, samples 29, 30, and 31), the phosphorus content was too low to permit of the

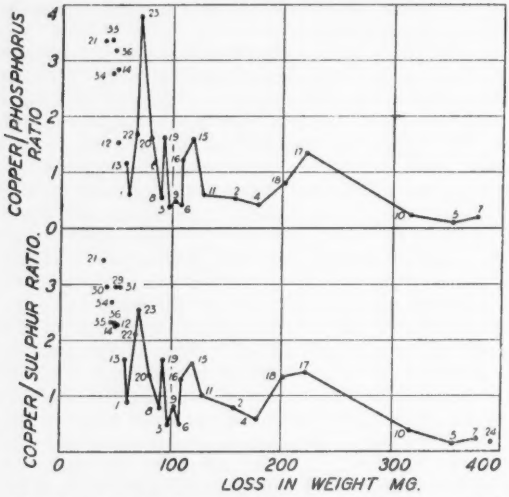


FIG. A.—Correlation of the Losses in Weight with the Copper/Sulphur and the Copper/Phosphorus Ratios of the Steels.

calculation of the copper/phosphorus ratio with any certainty. However, within this range the general direction of both curves was clearly the same.

Hence, he was forced to the conclusion that the data presented by the authors could have been equally well explained on the basis of the copper/phosphorus ratio of the steels as on that of the copper/sulphur ratio, which they had adopted. In view of the fact that the main piece of experimental evidence adduced in their paper could thus be used in support of both arguments, he thought it probable that the authors would admit that their subsidiary experiments on the effect of small amounts of metallic ions on the corrosion potential of two of their steels were not sufficient to justify their theory that sulphur alone was responsible for all the

effects observed by them, and that it was desirable to obtain further experimental data for materials with a varying sulphur but constant phosphorus content, and *vice versa*, before reaching a final conclusion.

With regard to the section dealing with "Factors Influencing the Anodic Process," paragraph (*d*), "The Influence of Copper Content," the authors stated that the mechanism of the action of copper had never been fully understood. Here he would refer them to a paper by Carius and Schulz,[1] whose views were very clearly expressed in the recent German textbook on corrosion, edited by Bauer, Kröhnke, and Masing.[2] According to these authors, the presence of copper in the steel affected its corrosion because in the corrosion process copper was dissolved and then redeposited on the steel. This copper layer became oxidised or corroded, and ultimately a film of copper, copper oxides, and hydroxides accumulated at the surface. The mechanical adhesion and presumably the composition of this layer varied with the corroding medium. If a continuous and adherent deposit was formed, the corrosion rate was diminished, as appeared to be the case in atmospheric corrosion; in various natural waters the deposit seemed to be flocculent, and little or no increased corrosion resistance was obtained. There was no doubt of the correctness of the fundamental basis of this theory; copper was certainly redeposited on a copper-bearing steel from certain acid solutions, as was obvious to anyone who pickled an ordinary and a copper-bearing steel side by side.[3] Indeed, Carius and Schulz were able to demonstrate by analysis that enrichment of copper in the corrosion product at the metal/rust interface actually occurred as a result of corrosion.

On the other hand, as the Corrosion Committee's researches and those of others had already demonstrated, there was no difference in the resistance to atmospheric corrosion of structural steels containing 0·2 and 0·5% of copper. The theory originally due to D. M. Buck and apparently endorsed by the authors, that the copper was beneficial in converting the sulphur into a comparatively harmless form, might explain why there should be a minimum copper percentage necessary to give the optimum corrosion resistance. As Bardenheuer and Thanheiser pointed out, however, this theory did not provide any explanation of the marked protective effect of copper in the presence of phosphorus, and, therefore, as already suggested, further experimental work was in his (Dr. Hudson's) view very necessary.

In conclusion, he rather thought that the authors were a little doubtful in their own minds as to the possible effect of the arsenic content of the steel on its corrosion rate. In their introduction

[1] *Archiv für das Eisenhüttenwesen*, 1929, vol. 3, p. 353.

[2] "Die Korrosion metallischer Werkstoffe," Band 1. Leipzig, 1936: S. Hirzel.

[3] *Cf.* K. Daeves and G. Tichy, *Stahl und Eisen*, 1929, vol. 49, p. 1379.

they stated that there was no evidence that arsenic had any effect, whereas in the "General Conclusions" they said it was quite possible that other elements present in mild steel, including arsenic, had appreciable effects. As a matter of fact, there was not much evidence, but such evidence as was available pointed to the conclusion that arsenic might affect the corrosion rate and would tend to reduce it. For example, there was no doubt that the presence of arsenic in acid solutions retarded the corrosion rate of iron very materially, as Watts and Whipple [1] had shown.

Mr. T. N. Morris and Dr. J. M. Bryan (Low-Temperature Research Station, Cambridge) wrote that they wished to congratulate Dr. Hoar and Mr. Havenhand on their paper, and to thank them and Mr. Macnaughtan for their kind remarks concerning the work the writers have been trying to do at the Low-Temperature Research Station on the steel base of tinplate. They were very glad indeed that the International Tin Research Council under Mr. Macnaughtan's inspiration had followed up this subject so successfully.

Perhaps the main consideration from their point of view as research workers interested in the canning industry was that Dr. Hoar's results clearly emphasised the need for carrying out practical canning tests with tinplates having steel bases of known behaviour towards citric acid. They had pressed for such tests for several years, but so far they had been unable to obtain sufficient material of the right kind. They hoped, however, that this paper would stimulate renewed interest in this subject, and that practical canning tests would be possible in the near future.

As regards the more theoretical aspects of the paper, they could only say that, in so far as the authors had covered similar ground to that covered by the writers, there was complete agreement between them and they had, of course, in attacking the subject more from the electrochemical and statistical points of view, extended and explained the writers' results in important respects and also broken new ground. The authors were to be congratulated particularly on their explanation of the action of tin ions in solution and for their statistical evidence of the effects of sulphur and copper in the steel on its corrodibility by citric acid. There was very little doubt, too, that Dr. Hoar had stated, in the section on "Factors Influencing the Cathodic Process," paragraph (*e*), "The Influence of Sulphur Content and Distribution in the Steel," the correct explanation for the severe attack on the edges of certain "slow"-corroding specimens at high acidity.

The action of phosphorus was still somewhat obscure, but the fact that a trace of phosphorous acid in the corroding liquid did not have any action comparable with that of sulphurous acid probably

[1] *Cf.* F. N. Speller, "Corrosion—Causes and Prevention," Second Edition, p. 185. New York and London, 1935 : McGraw-Hill Book Co. Inc.

supported the view, expressed in the section dealing with factors influencing the cathodic process (paragraph (*a*) "The Influence of Heterogeneity in the Metal"), with regard to any accelerating action which phosphorus might possess, when it was present in the steel. It appeared to the writers as being rather important to enquire how far the action of tin salts was specific towards sulphur as an accelerator. If they only affected the acceleration which was due to sulphur and left the effects of other elements untouched, they might be useful in separating and assessing the various accelerating influences in steel.

The remarks made by Principal Edwards and Dr. Hatfield on the emery-treatment of specimens would no doubt be dealt with fully by the authors, but since they also applied to the writers' work, they would like to ask them what other method they would propose. In their experience it had proved quite impracticable to carry out corrosion tests in dilute citric acid with untreated specimens, while pickling in stronger acids gave an uneven and unsatisfactory surface, with patches of undissolved oxide remaining here and there unless the pickling was pursued to such an undesirable extent that the surface became rough and pitted. If emery-treatment was carried out by hand, and was just sufficient to remove the film of oxide completely, reasonably reproducible results might be obtained. It was not necessary to assume that in the case of steels suitable for can-making the emery treatment would expose layers of metal differing radically in corrodibility from those at the original surface. In fact, if such an exposure occurred with such slight treatment as that given, it would be an indication that the steel was unsuitable.

Dr. U. R. Evans (Cambridge) wrote that in correlating the content of some element in steel with the corrosion velocity, *two procedures* were available. The choice was not simply a question of convenience; the two procedures were fundamentally different, and *if the wrong procedure was chosen for any given purpose, the conclusion would be wrong.* In the writer's opinion, the authors had chosen the *right procedure for their purpose.*

In the *first procedure*, all the factors were kept *constant* except the content of the element whose influence was to be tested. In the *pure-science* laboratory where the factors could be independently controlled, this was the correct method. It was, for instance, adopted recently in sixteen series of experiments by Mears and the present writer;[1] in each series all the factors except one were kept constant, and thus the influence of the factor under study was isolated. It would be permissible to use it in an industrial laboratory, provided that the industry in question had reached a stage at which the contents of all the elements could be controlled independently.

[1] R. B. Mears and U. R. Evans, *Transactions of the Faraday Society*, 1935, vol. 31, p. 527.

It was not generally suited for technical researches conducted in the interests of the users for reasons stated below.

In the *second procedure*, the materials were obtained in such a way that they formed " a *representative* sample of the population " of the variety of steel under consideration, and a correlation was then calculated between the content of the single element under study and the corrosion velocity, with all the other elements " roaming " naturally. Any attempt to *select* samples or to *prepare materials specially* for a test would give results *misleading to the user*, who had to take the materials as they came on to the market. This method, which had also been used by Mears,[1] was the correct one for any research conducted in the interests of the user, since in steel as it existed on the market to-day, a certain degree of correlation existed between the contents of the different elements.

The two procedures were liable to give different results, because the criterion adopted to decide whether the presence of an element was to be welcomed or otherwise, was different in the two cases. In the *first* procedure, the criterion was the sign of $(d\rho/da)_{b,\,c,\,d\,\ldots}$, where ρ was the corrosion velocity, a the content of the element which was varied and b, c, d . . . those of the other elements (their position in the suffix showed that they were held constant). If this differential was positive, the element was held to be dangerous; if it was negative, the element was welcomed. But in the *second* procedure the criterion was the sign of $(d\rho/da)_{E(b),\,E(c),\,E(d)\,\ldots}$, where $E(b)$, $E(c)$, $E(d)$ . . . were the " expected " values of b, c, d . . .; in the case of correlated elements the expected values would themselves be functions of a. This might be written

$$\left(\frac{d\rho}{da}\right)_{b,\,c,\,d\,\ldots} + \frac{\partial E(b)}{\partial a}\cdot\frac{d\rho}{db} + \frac{\partial E(c)}{\partial a}\cdot\frac{d\rho}{dc} + \ldots$$

Now $(d\rho/da)_{b,\,c,\,d\,\ldots}$ might sometimes differ in sign from $(d\rho/da)_{E(b),\,E(c),\,E(d)\,\ldots}$, and if so, the choice of the first procedure in cases where the second was appropriate would lead an element to be regarded as beneficial when it was really malign or *vice versa*. He hoped that the authors would not be persuaded by Principal Edwards to abandon a procedure which was essentially right, in favour of one which—for their main purposes—would be highly unreliable.

There were, of course, a number of varieties of the statistical method. In his opinion, the most suitable plan was to obtain a large number of samples at *random* which were representative of the *floating population* of material on the market, and calculate the *coefficient of correlation*

$$r_{a\rho} = \frac{\mu_{a\rho} - \mu_a\mu_\rho}{\sigma_a\sigma_\rho}$$

[1] R. B. Mears, *Iron and Steel Institute, Carnegie Scholarship Memoirs*, 1935, vol. 24, p. 69.

where μ and σ represented respectively the means and the standard deviations of the quantities suffixed. *Provided that the number of materials tested was sufficiently large*, and provided that they had been picked at random, a positive sign would indicate that the corrosion velocity ρ increased with a, a negative value that it diminished. This method gave the correlation obtained when all the factors except one were allowed *to roam* to an extent representative of the population of manufactured products. If it should be desired to "peg" a given variable, equations existed which would enable the statistician to obtain the appropriate "partial correlation coefficient"; such a calculation might be useful if one component of the steels was expensive. This subject had been discussed at length in connection with statistical methods as applied to biological problems, many of the classical papers being published in the journal *Biometrika*; some caution was needed in applying the principles to corrosion problems, but the majority were valid for every branch of knowledge, and the subject deserved more study than it appeared to have received, although statistical methods were used for assessing corrosion-resistance in some American and German steelworks; he believed the methods adopted were a little different from those advocated above.

One simple example—entirely imaginary—would serve to indicate a possible outcome of the principle laid down by Principal Edwards. If it was stipulated that the contents of all elements should be kept constant (other than the one whose influence was under examination) it was logical to stipulate that external factors, such as the rolling temperature, should also be kept constant. Imagine an element which had absolutely no influence on corrosion *as such*, provided that all the specimens tested were well rolled; imagine also that the presence of the element raised the rolling temperature needed to produce a good surface. Now, in the procedure advocated by Principal Edwards, a standard rolling temperature must be fixed for all materials. If a *low* temperature was chosen, the results would *appear* to show that the element increased the liability to corrosion, because the specimens rich in the element would possess an inferior surface; conversely, the choice of a *high* temperature would make it appear that the element diminished the liability to attack. *Either conclusion would mislead the user*, since presumably any manufacturer who provided a variety of steels containing the element in different amounts would not keep his rolling temperature constant, but would choose the best temperature for *each material*.

The fact that a high positive value of the total correlation coefficient might appear to attribute to an element a danger which was really due to some second factor with which the element tended to be associated was not a practical objection; it mattered little to the user whether sulphur was the direct cause of corrosion, or whether sulphur tended to be accompanied by some other factor

(such as blow-holes) which set up corrosion; in either case a high sulphur content in a material—in the absence of other evidence —should cause the material to be regarded as suspect. From the scientific standpoint, however, it was desirable to distinguish direct from indirect effects, and the correlation method clearly had its limitations.

He was especially interested in the correlation obtained between the potential of the specimen and the corrosion velocity. In cases where this simple relation was valid, the measurement of the potential should provide a very rapid means of measuring the corrosion velocity, and should constitute the accelerated corrosion test which was so often demanded. But to avoid disappointment in other cases, it should be pointed out that the potential would only be an indication of the corrosion velocity if three conditions were fulfilled :

(1) The variates must only affect the anodic polarisation, leaving the cathodic polarisation unchanged.

(2) The conductivity of the solution must be high enough to enable the intersection point of the two polarisation curves to be taken as representing the velocity.

(3) Most important of all, the variates must not affect the ratio of anodic and cathodic areas; since it was the current densities, not the currents, which fixed the polarisations, it was clear that any change in the areas would affect the gradients of the two polarisation curves.

Doubtless, in the present research, these conditions prevailed, except where the authors had made reservations to the contrary. But many cases were known where potential would be no guide to corrosion velocity. The reasons which made the three conditions necessary would become apparent to anyone who cared to read the papers in which the graphical method of obtaining the corrosion velocity from the polarisation curves was developed.[1]

Dr. O. Carrasco (Cirio, Naples, Italy) wrote that the authors' interesting paper should mark a very important step towards the *practical solution* of the most important problem which confronted the manufacturer of canned food-stuffs.

The results of his previous work on this subject [2] (the last of which was also published in the English journal *Food* [3]) confirmed his opinion on this point, and he was glad that the authors' conclusions gave further light on his results, thus reverting to an old saying of Evans that " We may hope to obtain metals resistant to

[1] U. R. Evans, *Journal of the Franklin Institute*, 1929, vol. 208, pp. 52–56. U. R. Evans and T. P. Hoar, *Proceedings of the Royal Society*, 1932, A, vol. 137, p. 359. S. C. Britton, T. P. Hoar, and U. R. Evans, *Journal of the Iron and Steel Institute*, 1932, No. II., p. 376.

[2] *Industria Italiana delle Conserve Alimentari*, 1934, vol. 9, p. 247.

[3] *Food*, 1934, vol. 4, p. 48.

corrosion rather by addition of suitable elements than by elimination of unsuitable ones."

AUTHORS' REPLY.

The AUTHORS submitted the following reply to the discussion and correspondence :

We must first thank Mr. Macnaughtan for his very kind remarks. The present work is no more than a demonstration of some important factors in the attack of mild steels by weak acids, and does not pretend to have exhausted the subject. If, arising out of the paper and the most stimulating discussion on it, future work brings to light yet other factors, we shall feel satisfied that the present research has served its purpose.

Mr. Macnaughtan rightly emphasises the utility of the statistical method in problems of this kind dealing with many unknown variable factors. It is the fashion in metallurgical research to lay great stress on the use of materials of known history, in the sense that every stage of their manufacture has been watched and controlled. Without doubt much valuable academic knowledge accrues from investigations which make this doctrine their foundation; but it is a pity that its wide acceptance has tended to discourage the use of the essentially more practical—although more mathematical—statistical method, which merely demands of its materials that they should be a random representative sample of the population under investigation.

Principal Edwards, in accusing us of using quite wrong evidence and utterly useless materials on which to base our results, asserts that the only scientific method in studies of this kind is that where all the variables except one are kept constant. This assertion is quite false, as all who are acquainted with the alternative statistical method will agree. As R. A. Fisher remarks,[1] " In expositions of the scientific use of experimentation it is frequent to find an excessive stress laid on the importance of varying the essential conditions *only one at a time*. . . . It is often supposed that to establish controlled conditions in which all of these factors except one can be held constant, and then to study the effects of this single factor, is the essentially scientific approach to an experimental investigation. This ideal doctrine seems to be more nearly related to expositions of elementary physical theory, than to laboratory practice in any branch of research. . . . In the state of knowledge or ignorance in which genuine research, intended to advance knowledge, has to be carried on, this simple formula is not very helpful."

Statistical analysis, properly applied to data obtained from a random sample of upwards of twenty individuals, can lead to

[1] R. A. Fisher, "The Design of Experiments," p. 96. 1936 : Oliver and Boyd.

results just as surely, and much more rapidly, than can the " synthetic " method favoured by Principal Edwards. Indeed, as Dr. Evans points out, the results obtained by the statistical method may have a much more direct bearing on practical problems than those obtained by the synthetic method.

If the appropriateness of the statistical method is agreed, Principal Edwards' other arguments with regard to the mode of preparation of the materials fall to the ground. The method presumes that the materials to be used form a representative sample of the " population " under investigation—in this case, tinplate steel-base. Therefore, any attempt to *select* materials, or to prepare them specially, would vitiate the results.

Furthermore, the " synthetic " method appears to have many disadvantages of its own, apart from the fundamental difficulty of preparing two ingots *exactly* alike save for one variable. This is not the place to subject the experimental results announced by Principal Edwards to criticism, for which opportunity will occur when his work is published. However, it seems to us that, although work on special materials, in which all the elements save one are held constant at arbitrary values, where the segregation is artificially minimised, the degree of hot-rolling kept small, and a surface of special quality aimed at, undoubtedly has value in elucidating the corrosion of such materials, nevertheless the results can have no particular significance with regard to the corrodibility of the very different tinplate steel-base. The influence of copper cited by Principal Edwards is a case in point. We do not question his result that copper has no retarding influence on the corrosion of " pure " steel, very low in sulphur and phosphorus; as Dr. Hudson points out, this agrees with the work of Bardenheuer and Thanheiser. But tinplate steel-base contains a good deal of sulphur and phosphorus, and the influence of copper on the corrosion of such material is a most definite retarding one, as shown by Bardenheuer and Thanheiser and in the present paper.

With regard to oxygen and phosphorus, we agree that these elements may have appreciable influences on the corrosion of mild steel; we have nowhere suggested that they do not. But since there are very few, if any, of our results for some 35 tinplate steels which cannot be explained in terms of sulphur, copper, and structure, we felt justified in laying emphasis on these three factors, at the same time pointing out that further work is required to elucidate other influences.

Principal Edwards several times implies that the present work has been carelessly planned. We can assure him that such was not the case. After preliminary trials with a few specimens of steel-base, it became clear that the best way to tackle the problem was by means of the statistical method, which is a perfectly reputable scientific procedure. We cannot but feel that had Principal Edwards been more aware of the established principles on which the

method rests, his somewhat sweeping criticism of our plan of work would not have been made.[1]

In reply to Dr. Hatfield's remarks endorsing Principal Edwards' standpoint with regard to the materials used for the research, we would like to thank him for his kind offer of co-operation, but at the same time to reiterate that no special material in any sense is required in a statistically planned research of this kind. Rather one should *avoid* selection; it is necessary that the sample should consist of individuals which are representative of the floating tinplate population, and are *not* necessarily "universally approved." Our materials, with the stated exceptions, are tinplate steel-base obtained from tinplate stock in a canning factory, or from South Wales tinplate and steel manufacturers, and we think they are reasonably typical of the material under study. In that sense they are materials of "known history." The information such materials give concerns the influence of variables *within the limits of variation found in present-day steel-base manufacture.* It is surely rational, from everyone's point of view, first to study the variables within these limits, before passing on to materials which are at present outside the range of the steel-base manufacturer.

We would like to discourage Dr. Hatfield's very old-fashioned view that the steel-base of tinplate is merely a "carrier for tin." If it were so, many of the difficulties encountered in canning practice would disappear. Even the best tinplate suffers damage to the coating in fabrication, owing to the large amount of mechanical working in the formation of seams; and it is usually at the seams in the can that the worst trouble is found. There is no doubt at all that the steel-base is a fruitful field for work aiming at improvement in the "tin can."

Dr. Hatfield's criticism of our method of preparing corrosion specimens seems to be not valid. The amount of metal removed from each specimen was a fraction of approximately 0·005 of the thickness of the metal in the case of the tinplate materials, which were all approximately 0·03 cm. thick. Dr. Hatfield *misquotes* the figure as "about 0·005 *in.*" and then says that that is an "unscientific expression"! In point of fact, the actual depth of metal removed was $0{\cdot}005 \times 0{\cdot}03 = 0{\cdot}00015$ cm. The following figures show the amounts (in milligrammes) of metal removed by the standard abrasion for both sides of 16 different specimens of mean initial mass 4·79 g.: 33·7, 25·5, 22·5, 22·6, 21·6, 29·3, 22·9, 30·7, 25·3, 28·2, 29·0, 24·8, 26·0, 19·7, 20·3, 23·1; mean 25·33 mg., probable error $\pm$ 2·64 mg. The divergences between specimens of the very small amount of metal removed can scarcely give rise to significant irregularities.

In general, abrasion is the only reasonably satisfactory method of preparing large quantities of specimens. It is dangerous to use as-rolled material, however apparently perfect the surface; experi-

[1] Fisher, *loc. cit.*, p. 2.

ence has shown that there may be great divergences between the oxide films on different as-rolled materials. Of course, in the present experiments with "white-annealed" steel-base, it was essential to remove the comparatively thick oxide film. Pickling in acid introduces two further difficulties; first, it is scarcely possible to pickle to a controlled depth with different materials, and, secondly, the uptake of hydrogen by the metal may seriously influence its subsequent electrochemical behaviour. Pickling in iodine solution avoids the latter difficulty; a few specimens were prepared in this way in connection with the present work, and gave corrosion results very close to those of abraded specimens of the same material.

We thank Mr. Whiteley for his remarks, evidently the fruit of detailed study of the paper. In reply, we would first state that preliminary experiments showed that the electrode potentials of half a dozen materials attained constant values within a very few hours; thus only the final values were measured in the main experiments, as a sufficiently good approximation.

We designated steel-base "rimming" steel, because British steel-base is often referred to as such, and because our surface sulphur analyses gave evidence of a pure rim. However, we understand that steel-base ingots are usually intermediate between the full rimming and the balanced type, the pure rim being rather thin. As regards corrosion, the visible behaviour of the molten ingot is less directly important than the nature of the rim produced.

With regard to the distribution of massive cementite, Mr. Whiteley will doubtless agree that visual examination of specimens gives one a better picture of the state of affairs than even the best photomicrograph; our assessment of the amounts of cementite was based on visual examination and is, we think, correct. We are inclined to assign the undoubted differences observed in the various steels to differences in the amount of cold-work before annealing, in the annealing time and temperature, and in the rate of cooling. We might mention that, in some work on the attack of steel by mineral acids, Tammann and Neubert [1] found that carbon in the pearlitic state had little effect, but when present as massive cementite gave rise to pronounced acceleration of the attack.

We think the exceptional capacity for oxygen depolarisation at *p*H 4·89 possessed by materials Nos. 31 and 36 is sufficiently proved by the fact that the *fall* in their corrosion when oxygen is removed is considerably greater than the average total corrosion of all the materials in the presence of oxygen at this *p*H.

With regard to the amount of dissolved sulphide present during corrosion, we would point out that, since the steel produces hydrogen sulphide as it dissolves, the concentration of sulphide in the first few molecular layers outwards from the metal is likely to be much higher than that in the bulk of the solution. Nevertheless we agree that

[1] G. Tammann and F. Neubert, *Zeitschrift für anorganische Chemie*, 1931, vol. 201, p. 225.

15 parts per million *added* sulphur is an " excess "—that is pointed out in connection with the results illustrated in Figs. 9A and 9B—but it is not an unreasonable excess. Part of the 15 parts per million was doubtless swept out by the hydrogen evolution, during the experiment; but in any case, as little as 0·5 part per million of added sulphur was found, in special experiments, to have a marked accelerating effect on the attack.

In reply to the correspondence, may we first thank Mr. T. N. Morris and Dr. J. M. Bryan very sincerely for their kind remarks; it is not always that those who follow up the pioneer work of others meet with such generous appreciation from the pioneers. We, too, hope it may soon be possible for the next stage, large-scale canning tests, to be undertaken.

So far as the present work goes, it has certainly appeared that tin salts are specific in that they remove dissolved sulphide and hence give retardation of corrosion; they do not, apparently, damp down the acceleration attributed to massive cementite. As Mr. Morris and Dr. Bryan point out, this is a point worth following up.

Mr. Morris and Dr. Bryan's remarks on emery treatment are welcome confirmation of our own views, stated above in reply to Dr. Hatfield.

Dr. Evans' support for the statistical method is most gratifying, and his very able analysis of the position is a valuable contribution to the discussion. There is no doubt that a random sample of 30 to 40 individuals, when examined by proper statistical methods, gives perfectly sound evidence concerning the population from which it was drawn. Moreover, it is possible to state arithmetically the " odds " that the results are " real " and not due to sampling errors; this we have done in the paper.

The " total correlation coefficient " between property A and property B is a measure of the extent to which A and B are directly *and/or indirectly* connected, as Dr. Evans points out. It does not show whether A causes B or B causes A, or whether some other factor C causes both independently. But where A is, say, sulphur content and B is corrosion rate, clearly B cannot cause A; thus a positive total correlation coefficient between sulphur content and corrosion rate must mean either that an increase of sulphur content causes an increase of corrosion rate, or that an increase of some other factor C, say, phosphorus content, is separately associated with both an increase of sulphur content and of corrosion rate. These possibilities may, however, be distinguished by means of " partial correlation coefficients." The first-order partial correlation coefficient between A and B (C being constant) is a measure of the correlation which would exist between A and B if C, a third factor, were kept constant at its mean value in the sample under investigation. By its use we may rule out any possible indirect effect of C. Furthermore, other factors, D, E, &c., may likewise be eliminated by finding second-, third-, &c., order partial correlation coefficients.

Thus it is possible to assess the *direct* influence of A on B when as many other factors as we please are kept constant at their mean values in the sample under study. We have employed this method below in examination of Dr. Hudson's suggestion regarding the copper/phosphorus ratio.

We would like to thank Dr. Hudson very much for his stimulating remarks, and for drawing attention to the work of Bardenheuer and Thanheiser, reference to which was unfortunately omitted in the advance copy through an oversight. The present results are very largely in line with those of the German workers, especially in the emphasis laid on the influence of copper in reducing the rate of attack of high-sulphur steels. We do not think, however, that the well established mechanism proposed by Carius and Schulz for the retardation of *atmospheric* attack by copper can have any relation to the mechanism by which copper restrains *weak acid* attack. It is doubtless true, as Dr. Hudson states, that copper is redeposited on *copper-bearing steels when they are pickled in mineral acids*. But the steels at present under consideration would not usually be termed "copper-bearing," as they all contain less than 0·2% of copper, and the majority less than 0·1%. Also, they were tested in the *scale-free condition* in *citric acid*, conditions by no means analogous to pickling. Actually, the "*fast*" steels often produced a *non-adherent* black deposit which evidently did not interfere with their rapid attack, whereas the "slow" steels usually gave much less deposit. In no case was any *adherent* deposit formed. Thus the retarding influence of copper is not due to the formation of especially protective corrosion-products, as in the case of atmospheric attack; and in view of the copper/sulphur ratio correlation, the electrochemical results and the work of Bardenheuer and Thanheiser, we preferred to adopt Buck's conception that copper tends to *directly* eliminate the effect of sulphur, and to offer a chemical explanation of it. It was partly because of the confusion existing in the literature regarding this point that we stated that the mechanism of the action of copper has "never been fully understood" (p. 258 P). We were referring to *acid attack*, not to atmospheric, as the context clearly shows.

As Dr. Hudson states, we are in doubt as to any possible influence of arsenic content on acid attack, though we do not see in our two remarks about arsenic the contradiction which he implies. It *is* "quite possible" that it has an influence, but there *is* "no evidence" for it. The retarding influence of arsenic ions in solution, and the *accelerating* influence of massive arsenic when coupled with steel, recently demonstrated by Watts,[1] are phenomena not necessarily connected with the influence of arsenic when present in traces in steel, and give no indication of what that influence may be.

Dr. Hudson's diagrams showing that the relation between the

[1] O. P. Watts, *Transactions of the Electrochemical Society*, 1935, vol. 67, p. 259.

copper/phosphorus ratio and the corrosion rate is similar to that between the copper/sulphur ratio and the corrosion rate are very interesting, and have prompted us to make a much more detailed statistical analysis of the present experimental figures. The results are surprisingly instructive, and show *inter alia* that the copper/phosphorus ratio relation is illusory, being due entirely to the fact that, in the steels used, there is a very strong correlation between the sulphur and phosphorus contents.

The procedure involves the calculation from the data of six total correlation coefficients, twelve first-order partial correlation coefficients, and six second-order partial correlation coefficients. The variates we are interested in are copper content, sulphur content, phosphorus content and corrosion rate in 0·1 *M* citric acid, which we shall designate *Cu*, *S*, *P*, and *R*, respectively. The formulæ used are as follows. If a variate X has a series of values X_1, X_2, . . . X_m in a sample of m individuals, with mean value $\frac{\Sigma X}{m} = \overline{X}$, and variate Y has corresponding values Y_1, Y_2, . . . Y_m, mean $\frac{\Sigma Y}{m} = \overline{Y}$, then their total correlation coefficient r_{XY} is [1]

$$r_{XY} = \frac{\Sigma(X - \overline{X})(Y - \overline{Y})}{\sqrt{\Sigma(X - \overline{X})^2 . \Sigma(Y - \overline{Y})^2}} = \frac{\Sigma XY - m\overline{X}\,\overline{Y}}{\sqrt{(\Sigma X^2 - m\overline{X}^2)(\Sigma Y^2 - m\overline{Y}^2)}}$$

The first-order partial correlation coefficient between X and Y when a further factor Z is kept constant is [2]

$$(r_{XY})_Z = \frac{r_{XY} - r_{XZ} . r_{YZ}}{\sqrt{(1 - r_{XZ}^2)(1 - r_{YZ}^2)}},$$

and the second-order partial correlation coefficient between X and Y when Z and W are kept constant is [2]

$$(r_{XY})_{Z,W} = \frac{(r_{XY})_W - (r_{XZ})_W(r_{YZ})_W}{\sqrt{\{1 - (r_{XZ})_W^2\}\{1 - (r_{YZ})_W^2\}}}.$$

All correlation coefficients lie between + 1 and − 1; a high positive value indicates that the variates increase together, a high negative value that one decreases with increase of the other. The chance that the value is "significant" may be deduced from a table such as Table VA. in Fisher's book.[3] The values for the correlation coefficients required, for the steels in Table V. and Table VI., a sample of 39 individuals, have been calculated; it is impossible to reproduce the arithmetical work, but it may be verified from the data of Tables I., II., and VI. of the present paper. The results are given in Table A.

[1] R. A. Fisher, "Statistical Methods for Research Workers," p. 169. 1934: Oliver and Boyd.

[2] *Ibid.*, p. 174.

[3] *Ibid.*, p. 196.

TABLE A.

Total Correlation Coefficients.	First-Order Partial Correlation Coefficients.	Second-Order Partial Correlation Coefficients.	P.
r_{SR} +0·2046	$(r_{SR})_{Cu}$ **+0·8489** $(r_{SR})_{P}$ −0·0349	$(r_{SR})_{Cu,P}$ **+0·7897**	4×10^{-10}
r_{PR} +0·2770	$(r_{PR})_{Cu}$ **+0·5852** $(r_{PR})_{S}$ +0·1938	$(r_{PR})_{Cu,S}$ −0·3384	4×10^{-2}
r_{CuR} **−0·5137**	$(r_{CuR})_{S}$ **−0·8861** $(r_{CuR})_{P}$ **−0·6897**	$(r_{CuR})_{S,P}$ **−0·8957**	$< 10^{-16}$
r_{SP} **+0·8099**	$(r_{SP})_{Cu}$ **+0·8124** $(r_{SP})_{R}$ **+0·8008**	$(r_{SP})_{Cu,R}$ **+0·7362**	5×10^{-8}
r_{CuS} **+0·6630**	$(r_{CuS})_{P}$ **+0·6677** $(r_{CuS})_{R}$ **+0·9146**	$(r_{CuS})_{P,R}$ **+0·8894**	$< 10^{-16}$
r_{CuP} +0·3691	$(r_{CuP})_{S}$ −0·3821 $(r_{CuP})_{R}$ **+0·6203**	$(r_{CuP})_{S,R}$ **−0·4627**	3×10^{-3}

The values printed in heavy type are "significant" in that they represent odds of better than 100 to 1 that the result is not due to chance sampling errors. In the case of the second-order partial correlation coefficients, the probability that the result is due to chance alone, P, has been calculated from tables.[1] P is seen to be remotely small in several cases. The more important results may now be precisely stated in words:

(1) r_{SP}, + 0·8099: Increase of sulphur content is associated with increase of phosphorus content.

(2) $(r_{SR})_{Cu}$, + 0·8489; $(r_{PR})_{Cu}$, + 0·5852: Increase of sulphur content and increase of phosphorus content are both associated with increase of corrosion rate when copper content is constant at 0·064%.

(3) $(r_{SR})_{Cu,P}$, + 0·7897: Increase of sulphur content is associated with increase of corrosion rate when copper content is constant at 0·064% and phosphorus content is constant at 0·040%.

(4) $(r_{CuR})_{S}$, − 0·8861; $(r_{CuR})_{P}$, − 0·6897: Increase of copper content is associated with decrease of corrosion rate both when sulphur content is constant at 0·039% and when phosphorus content is constant at 0·040%.

(5) $(r_{CuR})_{S,P}$, − 0·8957: Increase of copper content is associated with decrease of corrosion rate when sulphur content is constant at 0·039% and phosphorus content is constant at 0·040%.

(6) $(r_{CuS})_{P,R}$, + 0·8894: For constant phosphorus content (0·040%) and corrosion rate (119 mg. per 72 hr.), copper content must increase with increase of sulphur content.

[1] *See* R. A. Fisher, "Statistical Methods for Research Workers," Tables I., VA., VB. 1934: Oliver and Boyd.

These results confirm our original view that, under the average conditions prevailing in tinplate steel-base, an increase of sulphur increases the corrosion in citric acid, while an increase of copper diminishes the corrosion by reducing the harmful effect of sulphur. The apparent harmful influence of phosphorus is shown to appear only because high-phosphorus material is usually high in sulphur also. In fact, it is possible (since $(r_{I\cdot R})_{Cu,S} = -0{\cdot}3384$ and $(r_{Cu\cdot P})_{S,R} = -0{\cdot}4627$) that the real, direct effect of phosphorus is *beneficial*, in material of average S = 0·039%, Cu = 0·064%. We may note that Kendall and Taylerson [1] and Daeves [2] have found that, for attack by acid atmospheres, phosphorus is beneficial in steels containing copper. However, not much reliance is to be placed on the present calculation with regard to phosphorus, as the correlation coefficients concerned are barely large enough. Clearly more work on the influence of phosphorus is very desirable, as pointed out in the paper.

We are glad that Dr. Carrasco, representing a canning interest, regards the present results as a step in the right direction. We think, however, that the next stage should consist of a practical canning experiment designed to test the factors which the present work suggests may be important under canning conditions. One such research, carried out by the National Canners Association in the U.S.A., indicated the disadvantage of high-sulphur and -phosphorus steels, and gave some evidence for the beneficial effect of copper; but the work was planned and analysed before the newer statistical methods had come into use. The importance of correct planning in such experiments is obvious, and it is to be hoped that those who carry them out in the future will utilise the statistical method to the full.

In conclusion, it may be well to emphasise that the present results refer to tinplate steel *as at present manufactured* in Britain and elsewhere, in which the sulphur content varies between some 0·02 and 0·08%, and the copper between some 0·01 and 0·17%. It must *not*, for instance, be inferred that so-called " copper-bearing " steel (not normally used for tinplate), with upwards of 0·2% copper, is necessarily still less attacked by weak acid media than are steels *in the ordinary tinplate range* with a copper/sulphur ratio of not less than 2. Indeed, there is some evidence that increase of copper content above 0·2–0·3% may result is enhanced acid attack.

[1] V. V. Kendall and E. S. Taylerson, *Proceedings of the American Society for Testing Materials*, 1929, vol. 29, Part 2, p. 204.

[2] K. Daeves, *Archiv für das Eisenhüttenwesen*, 1935, vol. 9, p. 37.

THE INFLUENCE OF LIGHT ON THE ELECTRODE POTENTIAL AND CORROSION PHENOMENA OF MILD STEEL.[1]

By C. O. BANNISTER, M.Eng., A.R.S.M., and R. RIGBY, B.Eng., Ph.D. (Liverpool University).

Synopsis.

A review is given of previous work on the effect of light on the corrosion of iron and steel. For the present work an apparatus was used as described and illustrated in the *Monthly Journal* of the Institute of Metals, for February, 1936. This apparatus allowed of perfect control over the oxygen supply to the specimens under examination, the differences of potential between illuminated and non-illuminated specimens being registered by means of a thread recorder. Only slight differences are recorded in the absence of oxygen, but on aerating the electrode to be illuminated a marked response to illumination is shown. A record showing variations over four days is given; during the first two days the illuminated electrode becomes more cathodic, and during the second two days it becomes more anodic. The probable mechanism of the reactions is given, and a short comparison of the results with those obtained in the case of certain non-ferrous metals is added.

Introduction.

The authors have recently reviewed the literature on the influence of light on corrosion phenomena in the case of non-ferrous metals and have published work indicating a marked effect on electrode potential in the case of certain metals, and especially of zinc, lead, and aluminium.[2] The present work deals with mild steel from the same point of view.

Comparatively little has appeared in the literature on this particular branch of work, and the first recorded observation of the influence of light on the corrosion of iron was made by C. H. Cribb and F. W. F. Arnaud,[3] who reported that the rate of corrosion of iron specimens in water and various solutions exposed to diffused sunlight was appreciably greater than that of similar specimens kept in the dark. This result was attributed to the difference in illumination.

J. Newton Friend[4] reported some interesting results in 1911; he placed similar beakers containing similar pieces of pure iron foil and water in the light and in a dark cupboard respectively and found

[1] Received February 25, 1936.

[2] *Journal of the Institute of Metals*, 1936, vol. 58, p. 227.

[3] *Analyst*, 1905, vol. 30, p. 225.

[4] *Iron and Steel Institute, Carnegie Scholarship Memoirs*, 1911, vol. 3, p. 11.

an increased loss of weight in the light. Friend, W. West, and J. Lloyd Bentley [1] repeated these experiments, using a number of similar vessels, some opaque and others transparent, immersed in the same glass water-bath, the whole being subjected to diffused daylight. Using this arrangement, in which temperature differences were eliminated, they still found an increased loss in weight in the transparent vessels. The results also showed "a more pronounced accelerating influence on the initial oxidation of metallic iron, so that the formation of ferrous oxide outstrips that of ferric. In the dark, however, the two reactions apparently proceed at practically the same rate, so that the ferrous oxide is oxidised to rust as rapidly as it is formed."

Further work by Friend [2] confirmed the work of Cribb and Arnaud already quoted. For this he immersed electrolytic iron sheets in water, half the specimens in glass vessels and the rest in similar but opaque vessels, all the vessels being immersed in the same glass water-bath and the whole arrangement exposed to light. At no time was a greater temperature difference observed than 0·1° C. He noted the rates of corrosion in light and darkness to be in the ratio of 100 to 84·6.

G. M. Enos [3] also observed that light, particularly ultra-violet light, had an accelerating effect on the corrosion of iron and steel.

W. P. Wood [4] noted an increase in the corrosion of iron exposed to diffused daylight, the ratio of the corrosion with light to that without light being as 12 to 10. This is equal to a ratio of 100 to 83·3, which agrees well with Friend's ratio of 100 to 84·6.

In a paper by C. Benedicks and R. Sundberg [5] it is reported that the e.m.f.'s of stainless irons and steels are displaced 10–15 mV. by light. They state that even in the absence of oxygen (which they took precautions to exclude) some ferric ions must be produced, and they concluded that the e.m.f.'s observed are due to the displacement of the equilibrium ferrous $\rightleftharpoons$ ferric towards the left (ferrous). This is in accordance with the observation of P. Chastaing,[6] that ferrous sulphate is oxidised by red light and ferric sulphate is reduced by violet light.

The effect of light on the corrosion of steel in aqueous solutions is discussed by H. Endo and H. Sekiguchi,[7] who find the loss in weight of specimens in aqueous nitric acid, acetic acid, and ferric chloride to be greater on exposure to diffused light than in the dark.

[1] *Journal of the Iron and Steel Institute*, 1912, No. I., p. 266.
[2] *Iron and Steel Institute, Carnegie Scholarship Memoirs*, 1922, vol. 11, p. 116.
[3] *Industrial and Engineering Chemistry*, 1925, vol. 17, p. 793.
[4] *Transactions of the American Society for Steel Treating*, 1925, vol. 7, p. 321.
[5] *Journal of the Iron and Steel Institute*, 1926, No. II., p. 211.
[6] *Annales de Chimie et de Physique*, 1877, vol. 11 (5), p. 158.
[7] *Kinzoku No Kenkyu*, 1933, vol. 10, p. 166.

Effect of Light on the Electrode Potential.

Details of the Method of Investigation.—For the present investigation of the effect of light on the e.m.f. of mild steel specimens under corroding conditions, the apparatus was constructed with arrangements for the production of distilled water and the preparation of a solution of potassium chloride free from oxygen, to be used as the electrolyte, and also for the immersion of specimens of mild steel in this solution, still in the absence of oxygen. The specimens were contained in tubes of transparent quartz, and electrically connected to the terminals of a double-thread recorder through a resistance of 5000 ohms. The recorder drum made a complete revolution in 25 hr., and the black thread was arranged to register zero while the red one registered the changes of e.m.f. taking place,

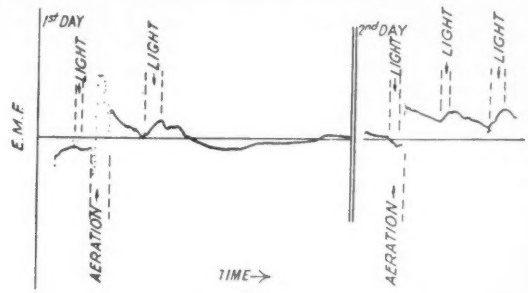


Fig. 1.

the threads recording alternately, every quarter-minute. Arrangements were also made for the admission of oxygen to either of the quartz tubes, as desired. The specimens of mild steel used consisted of rods each $\frac{1}{4}$ in. in dia., and each specimen was waxed to within 1 in. of the bottom in order to eliminate disturbances due to possible local oxygen concentration, thus giving an actual working length of 1 in. of metal. For the supply of oxygen to one or other of the metal electrodes heavy-walled glass tubes of 1 mm. bore and turned up at the ends were arranged to deliver oxygen under the ends of the two specimens.

The electrolyte consisted of a 3% solution of potassium chloride made and delivered to the tubes containing the specimens in a current of oxygen-free nitrogen. Completion of the electrolyte circuit was effected by a 4-mm. glass U-tube connecting the quartz tubes and fitted at its lowest point with a T-piece through which the electrolyte was admitted.

The results obtained are shown in Figs. 1 and 2, and represent the changes taking place during four consecutive days, during which time the sample of metal to be illuminated was connected to the

negative terminal of the recorder. A quartz mercury vapour lamp with 225 watts actually in the arc was used as an illuminator, at a distance of 3 ft. from the tubes.

With reference to the curve in Fig. 1, for the first day: On admitting the electrolyte to the quartz tubes containing the specimens the recorder was started, and the curve obtained on the drum commenced below the zero line, but showed an upward tendency towards this line, and then became horizontal. At this point the specimen was illuminated, and a slight depression of the curve away from the zero line immediately followed, indicating that the electrode was anodic at this point.

After removal of the light, the curve recovered from the depression, and then a small quantity of oxygen was admitted to the tube; this resulted in a rapid disturbance of the e.m.f., causing the specimen to become markedly anodic, then more markedly cathodic for some minutes. The addition of oxygen caused the pointer of the recorder to move to the extreme edge of the chart, and in order to reduce it to a more suitable position for recording, one or two bubbles of oxygen were admitted to the tube containing the electrode connected to the positive terminal of the recorder. This immediately reacted in the reverse direction, bringing back the pointer for a moment below the zero line, then to a position approximately halfway between the extreme position and the zero line, from which position it slowly fell to the zero line in the course of two hours. At this point the electrode was illuminated and a rise in e.m.f. was recorded, which attained a value of 0·06 V. during one hour. On removal of the light, the e.m.f. fell rapidly at first, then more slowly, crossed the zero line and returned to just above this line. On the second day, as depicted in Fig. 1, the e.m.f. commenced by falling slowly, and when the specimen was illuminated (at the point indicated in the diagram) it fell more rapidly, the electrode becoming anodic; on removal of the light a change in the direction of the curve took place. At this point oxygen was again admitted to the electrode tube, with an immediate response, the direction of the curve showing the specimen to have become cathodic. After this the curve fell steadily towards the zero line, and when its direction was confirmed, the electrode was illuminated, with an immediate response; on removal of the light, the curve again fell, but responded once more when illuminated, and again fell on removal of the light.

On the third day (Fig. 2), the e.m.f. was giving a steady value near the zero line, and on illuminating the tube a small response only was obtained, the downward direction indicating that the specimen was becoming more anodic; the curve took the upward direction on the removal of the light. A small supply of oxygen to the tube was now given, resulting in an immediate increase in the e.m.f., which slackened down, however, giving a horizontal portion; on illuminating the specimen a small depression occurred, followed by a recovery on the removal of the light; a further depression

occurred on illuminating a second time, followed by a recovery, a horizontal portion, and then a gradual fall to a steadily decreasing value. On the fourth day oxygen was again supplied, giving rise to a gradual increase in the e.m.f., which was followed by a depression on the application of light, as indicated on the curve (Fig. 2, fourth day), with recovery on removal of the light; this was followed by a little unsteadiness of the curve, and when it had become more regular a further depression occurred on the application of light, with a recovery on its removal. By this time the electrode had become heavily encrusted with rust and the solution strongly coloured with iron salts.

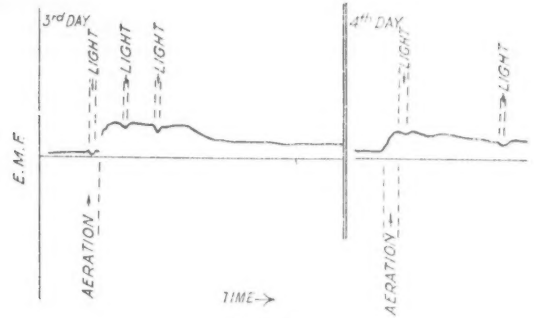


FIG. 2.

Interpretation of Results.—In considering the e.m.f./time curves obtained with mild steel it must be remembered that iron is a metal with two valencies, and forming two series of salts, namely, ferrous and ferric, so that in the apparatus used there will be changes in the e.m.f. values due not only to changes in which the electrode takes part, but also to possible changes in the ferrous $\rightleftharpoons$ ferric equilibrium in the electrolyte.

As pointed out in the historical references in the introduction, it has been known since 1877 that the direction of the equilibrium ferrous $\rightleftharpoons$ ferric in solutions is displaced towards the left (ferrous) by sunlight, and this type of reaction has received a considerable amount of attention. Benedicks and Sundberg[3] also have constructed a photo-electric cell with two pieces of stainless steel in ferrous sulphate solution, based on this reaction, and it has been found that the movement of the e.m.f. due to a change of this nature is in a direction tending to make the illuminated specimen anodic, which is directly opposite to the results obtained with the elements zinc and aluminium, which have only one valency.

Following now the changes in e.m.f. depicted in the curve for the first day (Fig. 1, first day), the first effect of light in the absence

of oxygen is to render the illuminated specimen anodic to the other specimen, and this is probably due to the fact that, as pointed out by Benedicks and Sundberg, even in the absence of oxygen some ferric ions must be present in the solution, and by the action of light these are reduced to ferrous ions, thus causing a difference in the equilibrium ferrous $\rightleftharpoons$ ferric in the two tubes, resulting in an e.m.f. of about 0·01 V., as shown in the curve.

On removing the light and admitting oxygen to the tube, there is an immediate response, the specimen becoming momentarily anodic, probably owing to the stirring of the electrolyte, and then strongly cathodic, owing partly to the oxidation of ferrous ions to ferric, but to a much larger extent to the formation of an oxide film on the specimen. It is interesting to note that by the addition of oxygen to the second tube also, the e.m.f. can be adjusted to any required position on the scale. Having thus adjusted the position, the curve shows a gradually diminishing e.m.f. until it reaches the zero line, this reduction being due to the diminishing oxygen content of the electrolyte and to reduction of ferric ions to ferrous by the iron electrode.

If the specimen is illuminated again, it becomes cathodic, this being a consequence of the catalytic action of the light in aiding the formation of an oxide film on the electrode, but the e.m.f. produced by this reaction is somewhat reduced by a reverse e.m.f. due to reduction of ferric to ferrous ions by the action of the light.

On removal of the light, the e.m.f. falls irregularly, crosses the zero line, then rises slightly, becomes horizontal, then rises above the zero line, and becomes fairly steady just above zero.

On the second day, as shown in the curve (Fig. 1, second day), the first response to light was to make the electrode anodic, probably because of a low concentration of oxygen in solution and the consequent predominance of the e.m.f. due to the displacement of the ferrous $\rightleftharpoons$ ferric equilibrium.

When the light was removed, a slight reversal of the e.m.f. was produced, as indicated on the curve, and at this point a few bubbles of oxygen were admitted to the tube, which resulted in the electrode again becoming cathodic; the e.m.f., however, fell steadily from this point, but the admission of light reversed this tendency twice, as depicted in the curve, the reactions being undoubtedly those indicated as taking place, with similar results, on the first day.

On the third day, as indicated in the curve (Fig. 2, third day), the first action of light was again to render the electrode anodic, and the action of added oxygen was to reverse this effect, as is seen by the sudden momentary rise in e.m.f., followed by a fall and a gradual rise and a steady period. At this stage, the action of light following aeration is different from that obtained on the first and second days, as it has the effect of rendering the electrode more anodic. This result is due to the fact that the action of the light in the reduction of ferric to ferrous ions predominates, owing to the high

concentration of iron in solution in the electrolyte, which by this time had become strongly tinted with ferric salts. Exactly the same type of reactions take place on the fourth day, as shown in the curve (Fig. 2, fourth day), aeration rendering the electrode more cathodic and light having only a slight effect in the opposite direction.

Comparison of Results with those Obtained in the Case of Certain Non-Ferrous Metals.—It may be of interest to note that, in the case of zinc and aluminium—metals having but one valency—the influence of light has been found to enhance the effect of aeration and render the illuminated electrode cathodic, or to increase the e.m.f. in this same direction. In the case of copper, a metal possessing two valencies, the differences of e.m.f. between the illuminated and the non-illuminated electrode were found to be more complex and to vary with the rate of supply of oxygen and other factors. The variation in the proportions of cuprous to cupric oxides present on the electrode also plays an important part in the reactions, and in the direction of the e.m.f. The metal iron reacts to some extent in the same manner as copper, for in addition to the action of the electrolyte and of oxygen on the metal, there is the influence of the equilibrium between the ferrous and ferric ions in the electrolyte to be taken into account; these factors include the conversion of ferrous to ferric iron by oxygen during aeration, the conversion of ferric to ferrous iron by the metallic electrode or by hydrogen, and the influence of light on these several reactions, some of which have been recognised for many years.

DISCUSSION.

Dr. U. R. EVANS (Cambridge) said the Institute should be extremely grateful to the authors for their study of a much neglected but, as he thought they had proved, very important matter. When the present paper was read in conjunction with the other paper to which Professor Bannister had referred,[1] he thought it might be accepted as an undoubted fact that there was a genuine photochemical action. But the authors had shown that the effect of radiation was complicated; it seemed fairly certain that there were at least two different influences at work, because the authors had shown that on some occasions the light shifted the potential in one direction and on other occasions in the opposite direction; it was even possible that there were more than two effects at work. He would try to suggest some ways in which radiation might reasonably be supposed to modify the potential, but he would first confess that he was not a photochemist and his remarks should not be regarded as authoritative; within the last ten years photochemistry had become changed out of all recognition, owing to the development of quantum mechanics.

He spoke of "radiation" rather than light, because the rays which affected their eyes were hardly more than an octave in the long keyboard of tones known to science. These might produce two main effects; *all* radiation, when it was absorbed, produced heat; *some* radiation, and particularly that of short wave-length (or high frequency) could in suitable circumstances produce chemical action. Imagine radiation falling on a vessel containing a metal specimen surrounded by liquid. If the radiation was absorbed by the glass or by the liquid, thermal convection currents would rise along the walls of the vessel, which would generally increase the supply of oxygen to the metal, and in most cases shift the potential in the cathodic direction. If, on the other hand, the radiation was not absorbed by the glass or liquid, but reached the metal, the convection currents usually moved in the opposite direction, and might sometimes, but not always, have the opposite effect on the potential.

Coming to the true photochemical effect, it might act in a number of ways. If the radiation catalysed the direct combination of oxygen with the metal, the oxide film formed would tend to shift the potential in the cathodic direction; if it catalysed the depolarising effect of the oxygen, that would again generally tend to make the potential more cathodic. On the other hand, as the authors had pointed out, if the radiation upset the equilibrium between ferric and ferrous salts, it might make the potential more anodic. He could suggest still other ways in which radiation might shift the potential.

[1] *Journal of the Institute of Metals*, 1936, vol. 58, p. 227.

The point was that there might be six or more effects superimposed. Possibly many of them were unimportant, but before a detailed interpretation could be attempted, it would, he thought, be necessary to separate them. The question arose, therefore, as to how to separate them. He thought that the thermal effects could be eliminated if the liquid was kept in such a state of agitation that any thermal convection was small compared to this mechanical movement. He believed that in photochemical work that was the only way to get rid of thermal disturbances, because the precautions which would be taken in ordinary electrochemical work (such as avoiding the use of a luminous heater for the thermostat, shielding from stray radiation, increasing the heat capacity by means of a large conducting mass, and so on) were all useless in the present case. Even filters were only partially helpful, because the actual radiation which was being studied would itself produce heat besides chemical action where it was absorbed.

With regard to the different photochemical actions which might be present, he thought that it would be necessary to rely upon differences in threshold wave-lengths in order to separate them. Speaking generally, if one plotted quantum efficiency against wave-length, one would find that down to a certain threshold wave-length there was very little effect, but that wave-lengths shorter than this threshold value produced photochemical action; in general the threshold would occur at a different wave-length for different reactions. If the various thresholds were well separated and sharply defined—unfortunately they were never as sharp as one would like—one might hope to separate out the different effects, but using in turn different bands of wave-length. He expressed the hope that the authors would be encouraged by the success of their present research to carry the matter still further, and to try, in one way or another, to separate out the various effects that might be present. If that were done, he thought a detailed interpretation of the work could be attempted; at the present moment, such an interpretation would be premature.

AUTHORS' REPLY.

The AUTHORS, in reply, thanked Dr. Evans for his most illuminating remarks and agreed with all he had said. There were possibly far more effects operating in the influence of radiation on the corrosion phenomena of metals than they had found, but they had observed the two effects dealt with in the paper in the case of iron, and they considered that it was sufficient to justify their drawing attention to the subject in order that it might receive more widespread attention and lead to further results.

They took the usual precautions in regard to heat energy, using dilute copper sulphate to absorb the longer radiations and

also in order to eliminate heating by the absorption of energy. The vessels were of transparent quartz, a potassium chloride solution was used for which no data could be found indicating decided absorption in any region on the wave-lengths used, and the iron specimens had no definite absorption band in that region of the spectrum. Moreover, whilst in the case of the iron the solution was not particularly stirred, in the case of some of the non-ferrous metals the solution was in a distinct state of agitation during the period of illumination, and the effect was obtained in the same direction and to about the same extent, which would seem to indicate that too large an effect due to heating was not being obtained.

With regard to the methods of sorting out the different effects, the authors were afraid they had obtained no indication of other reactions tending to make the specimen cathodic; but that two effects at least were operating in the case of iron was shown by the fact that in one case the specimen illuminated became cathodic and in the other case anodic. They had put down what they considered to be a possibility with regard to the interpretation of these effects, but at present they agreed that they could not go further than that broad outline, on the evidence so far available, and that was the point of view they put forward before the Institute of Metals.

THE BEHAVIOUR OF FIVE CAST IRONS IN RELATION TO CREEP AND GROWTH AT ELEVATED TEMPERATURES.[1]

By H. J. TAPSELL, A.C.G.I., M. L. BECKER, Ph.D., B.Met., and C. G. CONWAY, B.Sc. (National Physical Laboratory).

Summary.

Owing to the scarcity of information regarding the properties of ordinary and alloy cast irons at the temperatures of superheated steam, an investigation was undertaken with the view of determining to what extent cast irons have useful properties at these temperatures. The work has consisted in the study of the creep and growth of ordinary cast iron, nickel-chromium cast iron, Silal, Nicrosilal, and Niresist cast irons mainly between 370° C. (700° F.) and 538° C. (1000° F.), and an examination of the effect of prolonged heating on the microstructures of the irons. A few comparative creep and growth tests have been made at 850° C. on the Silal, Niresist, and Nicrosilal cast irons, since the last-mentioned iron has been developed chiefly for use at relatively high temperatures.

The results of the investigation show that the rates of creep and growth of ordinary grey cast iron and nickel-chromium cast iron may be considerably reduced by preliminary heat treatment below the critical temperature for a suitable period, and, for that reason, these irons in the heat-treated condition may have additional useful application. The heat treatment lowers the tensile strength at air temperature of the ordinary cast iron, but has much less effect on the strength of the nickel-chromium cast iron. The Silal cast iron has properties of the same order as those of the ordinary and nickel-chromium cast irons in their heat-treated condition.

The creep and growth of the samples of austenitic Nicrosilal cast iron at 450° C. (842° F.) and 538° C. (1000° F.) are very little different from those of ordinary cast iron in the as-cast condition; the poor properties of the Nicrosilal cast iron are probably due to the instability of the austenite at both temperatures.

Good resistance to growth and creep at 450° C. and 538° C. is shown by the Niresist cast iron, which is also austenitic; actually, it possesses better resistance to growth at 538° C. than at 450° C.

At 850° C. the Nicrosilal cast iron is superior to both the Silal and Niresist cast irons.

Introduction.

It appears to be generally considered that ordinary cast iron is serviceable only at comparatively low steam temperatures, owing largely to dimensional changes at higher temperatures, *i.e.* "growth," accompanied by loss of strength. In Great Britain the general view appears to be in favour of limiting the use of ordinary cast iron to a maximum steam pressure and temperature of 250 lb. per sq. in. and

[1] Communication from the National Physical Laboratory received February 13, 1936.

400° F. respectively. According to the Boiler Code of the American Society of Mechanical Engineers the use of cast iron for pressure containing parts is limited to a maximum temperature of 450° F.

Some short investigations [1] have been made of the creep and growth of ordinary cast irons at temperatures below the critical range, but so far as the authors are aware the comparative growth/time characteristics of ordinary and alloy cast irons in the steam temperature range of 700–1000° F. have not been demonstrated, and no data relating to the comparative creep properties of the irons in that temperature range have appeared in the literature.

The work described in this paper was, therefore, undertaken with a view to determining to what extent ordinary and alloy cast irons have useful properties at high steam temperatures, and whether they are capable of further application at these temperatures. Five typical irons were selected in consultation with Mr. J. G. Pearce, Director of the British Cast Iron Research Association, who kindly arranged for the supply of material.

The materials were: Ordinary grey cast iron, nickel-chromium iron, Silal, Nicrosilal, and Niresist. In the main, the creep and growth tests have been carried out within the range 700° F. (370° C.) to 1000° F. (538° C.), but the results of some comparative tests at 850° C. on the high-alloy irons have been added to the paper. A study has been made of the microstructures of the irons as tested, and of the modifications produced by prolonged heating at the testing temperatures.

The work was of an exploratory nature, and was discontinued when it reached a stage which, it was thought, had then provided results which might encourage industry to proceed with further research on parallel lines.

Materials Examined.

Cast bars, approximately 1·2 in. in dia., of each of the five irons were obtained by arrangement with Mr. J. G. Pearce, Director of the British Cast Iron Research Association. The chemical composition of the irons is given in Table I. The ordinary cast iron was supplied as being typical of a good engineering iron, but the combined carbon content was unusually high. It was probably rather hard, but this, it was believed, was in line with modern tendencies. The nickel-chromium iron was also typical of an improved high-class iron, and the particular composition was considered to be suited for rather thinner castings than the ordinary iron. The sample of Silal iron contained slightly more carbon than was usually considered desirable, and the phosphorus content was above the usually recommended value. Experiments with

[1] Honegger, "Das Gusseisen," Eidgenössiche Materialprüfungsanstalt an der E. T. H. in Zürich. Diskussionsbericht Nr. 37. Zurich: December, 1928. E. Piwowarsky and O. Bornhofen, *Archiv für das Eisenhüttenwesen*, 1931, vol. 5, pp. 163–166.

TABLE I.—*Chemical Composition of the Cast Irons.*

	Ordinary.	Nickel-Chromium.	Silal.	Nicrosilal. (1st Batch.)	Nicrosilal. (2nd Batch.)	Niresist.
Total carbon, % .	3·29	3·19	2·39	1·75	1·80	2·44
Graphitic carbon, % . .	2·19	2·54	2·31	1·47	1·53	1·70
Combined carbon, % (by difference) . .	1·10	0·65	0·08	0·28	0·27	0·74
Silicon, % . .	1·27	2·13	5·72	5·84	4·43	1·11
Manganese, % .	0·28	0·58	0·67	0·68	0·60	0·76
Sulphur, % .	0·12	0·090	0·063	0·039	0·046	0·057
Phosphorus, % .	0·72	0·80	0·30	0·045	0·036	0·26
Nickel, % . .	...	0·67	...	17·72	18·67	16·56
Chromium, % .	...	0·34	...	2·10	2·56	3·30
Copper, % . .	...	...	...	...	...	7·30

the first batch of Nicrosilal iron indicated that its composition was rather critical, and a second batch of slightly different composition was briefly examined at the suggestion of Mr. J. G. Pearce. The Niresist iron was probably fairly typical in composition, but the carbon and manganese contents were somewhat lower than the values recommended by certain authorities.[1]

The microstructure of the irons in the as-received condition is described in conjunction with the changes occurring during creep and growth tests under the appropriate headings below.

BEND TESTS AT AIR TEMPERATURE.

To provide an indication of the quality of each of the irons a few bars were subjected to the transverse bend test. The unmachined test bar, approximately 1·2 in. in dia., was rested on cylindrically seated blocks 18 in. apart, and was gradually loaded at the centre of the span, the loading die being 2·5 in. in dia. Readings of the deflection were taken during loading in order to determine the maximum deflection at fracture. At least two tests were made on each iron, and the results are shown in Table II.

Certain bars were found to contain blow-holes, and others were somewhat porous; some variation in modulus of rupture was, therefore, to be expected, since the bend test bars were chosen haphazardly from the batches supplied. In all the further tests to be described, machined specimens were used, and only those were tested which, during machining, were found to be reasonably free from blow-holes and porosity.

[1] J. S. Vanick and P. D. Merica, "Corrosion- and Heat-Resistant Nickel-Copper-Chromium Cast Iron," *Transactions of the American Society for Steel Treating*, 1930, vol. 18, p. 923.

TABLE II.—*Results of Bend Tests.*

Material.	Mean Dia. of Test Bar. In.	Rupture Load. Tons.	Modulus of Rupture. Lb. per sq. in.	Maximum Deflection at Fracture. In.
Ordinary iron.	1·20	1·05	62,400	0·167
	1·28	1·00	48,800	0·138
	$1·27_5$	0·81	40,350	0·097
Nickel-chromium iron.	$1·22_5$	1·166	65,130	0·155
	$1·23_5$	1·40	76,300	0·180
	1·24	1·285	68,800	0·184
Silal iron.	1·20	1·10	65,400	0·172
	1·23	1·10	60,750	0·201
Nicrosilal iron. (1st Batch)	$1·22_5$	0·96	53,740	0·60
	$1·22_5$	0·965	53,900	0·45
Niresist iron.	$1·22_5$	0·88	49,015	0·17
	1·25	1·00	52,560	0·21

SHORT-TIME TENSILE TESTS.

Tensile tests were made at air temperature, 370° C. (700° F.), 450° C. (842° F.), and 538° C. (1000° F.). Two sizes of specimens, 0·564 in. and 0·35 in. in dia., both of 2 in. gauge length, were used for the tests at air temperature, but specimens of 0·35 in. dia. only were used for the high-temperature tests. The 0·564 in. dia. specimens were machined from the full sections of the bars, whilst the 0·35 in. dia. specimens were machined from half sections. In all the tests, the load was applied at a rate of approximately 1 ton per sq. in. per min., and at least two tests were made at each temperature. The results of these tests are given in Table III.

For the first three irons in Table III. the ultimate stresses at air temperature for the 0·564 in. dia. specimens are higher than those obtained with 0·35 in. dia. specimens, but the reverse applies in the case of the Nicrosilal iron and the Niresist iron. The short-time tensile strengths of the ordinary, nickel-chromium and Silal irons are not impaired until a temperature of 450° C. (842° F.) is exceeded; the nickel-chromium iron shows an appreciable increase in strength at 370° C. (700° F.). Both Niresist and Nicrosilal irons have low strength, but Nicrosilal exhibits the best elongation values over the range of test temperatures, whilst Niresist shows the least rate of decrease in strength with temperature.

CREEP AND GROWTH TESTS.

The possible utility of cast irons from the point of view of the high-temperature steam-plant manufacturer depends not only on the ability of the irons to stand stress at high temperatures, but

TABLE III.—*Results of Short-Time Tensile Tests.*

Temperature of Test. °C.	Ultimate Stress. Tons per sq. in.				Approximate Elongation on Gauge Length. $L = 4\sqrt{\text{Area}}$. %		
	Individual Tests.			Average Value.	Individual Tests.		
	(1)	(2)	(3)		(1)	(2)	(3)
Ordinary iron.							
Air (0·564 in. specimens)	16·0	15·4	17·5	16·3	0·5	0·5	0·5
Air (0·35 in. specimens)	14·6	15·8	15·4	15·3	0·5	0·5	0·5
370 " "	16·6	14·9	...	15·7	1·0	0·5	...
450 " "	14·9	14·8	...	14·8	0·5	1·0	...
538 " "	8·9	10·9	...	9·9	2·5	1·5	...
Nickel-chromium iron.							
Air (0·564 in. specimens)	16·0	16·1	16·0	16·0	0·5	0·5	0·5
Air (0·35 in. specimens)	14·3	12·3	...	13·3	0·5	0·5	...
370 " "	16·5	16·8	...	16·6	0·5	0·5	...
450 " "	15·3	12·7	...	14·0	1·5	1·0	...
538 " "	10·4	7·2	10·7	9·4	1·0	1·0	1·0
Silal iron.							
Air (0·564 in. specimens)	14·4	13·4	14·8	14·2	0·5	0·5	0·5
Air (0·35 in. specimens)	14·3	15·1	12·3	13·9	0·5	0·5	0·5
370 " "	11·4	15·8	...	13·6	0·5	0·5	...
450 " "	16·2	11·3	15·2	14·2	1·0	0·5	0·5
538 " "	8·6	9·1	...	8·8	1·0	0·5	...
Nicrosilal iron (1st batch).							
Air (0·564 in. specimens)	9·4	9·5	9·5	9·5	1·5	1·5	1·5
Air (0·35 in. specimens)	10·8	11·7	...	11·2	1·5	2·5	...
450 " "	7·9	8·7	...	8·3	0·5	1·5	...
538 " "	7·7	7·7	...	7·7	1·5	1·5	...
Niresist iron.							
Air (0·564 in. specimens)	8·7	8·8	10·7	9·4	0·5	0·5	0·5
Air (0·35 in. specimens)	11·6	11·1	...	11·3	0·5	0·5	...
450 " "	9·8	10·7	...	10·2	0·5	0·5	...
538 " "	9·5	9·8	...	9·6	0·5	0·5	...

also on their resistance to growth or deformation in the absence of stress. Measurements of linear growth have, therefore, been made, using test-pieces of the same dimensions as those used for the creep tests, the test-pieces being free from any appreciable tensile stress. The measured growth could, therefore, be compared with the deformation due to both stress and growth in the creep tests. It cannot be stated whether or not the process causing linear growth is modified by applied stress; the deformations at different stresses in the creep tests do not, therefore, necessarily include a constant quantity attributable to growth, although, in general, the results obtained are not in disagreement with such an assumption.

The specimens used for the creep and growth tests were 0·30 in. in dia. and of 2 in. gauge length, and were machined from half-sections of the bars. Tests were made at 450° C. (842° F.) and 538° C. (1000° F.), with additional creep tests at 370° C. (700° F.) in the case of the ordinary, nickel-chromium, and Silal irons. In all the tests the temperatures were maintained within $\pm 2\frac{1}{2}$° C.

At an early stage in the experiments it was observed that different bars of both the ordinary and the Silal cast iron appeared to have somewhat different creep properties, and comparative creep tests were, therefore, made on four bars of each iron to determine the order of variation. The tests were carried out at 450° C. (842° F.) only. The results of the comparative creep tests on different bars are given in Table IV.

TABLE IV.—*Results of Comparative Creep Tests at 450° C. on Different Bars of Ordinary and Silal Cast Irons.*

Bar No.	Stress Applied. Tons per sq. in.	Rate of Strain at 15 Days. In. per in. per hr.	
		Individual Values.	Mean Value.
Ordinary Cast Iron.			
1	4	$0{\cdot}0000017_9$	$0{\cdot}0000026_5$
2	4	$0{\cdot}0000035_4$	
3	4	$0{\cdot}0000020_8$	
4	4	$0{\cdot}0000032_1$	
1	6	0·0000075	0·0000096
3	6	0·0000117	
Silal Cast Iron.			
1	5	$0{\cdot}0000010_4$	$0{\cdot}0000016_7$
3	5	$0{\cdot}0000008_3$	
4	5	$0{\cdot}0000031_3$	
2	4	$0{\cdot}0000012_5$	$0{\cdot}0000011_9$
3	4	$0{\cdot}0000005_4$	
4	4	$0{\cdot}0000017_9$	

It will be seen that there was considerable variation in the creep rate at 15 days of different bars of each iron. The variations encountered cannot be attributed to differences in the rates of growth of the bars at 450° C., since the rate of growth was found to be of the order of only $1{\cdot}2 \times 10^{-7}$ in. per in. per hr. in the case of the ordinary cast iron, and less than 5×10^{-8} in. per in. per hr. in the case of the Silal cast iron. Comparative creep tests were not made on different bars of the other irons; the subsequent creep tests, however, indicated that they were not free from variability.

The main experiments were undertaken in order to provide an idea of the magnitude of the creep and growth of each of the five irons at the test temperatures. Later it is explained how both the creep and the growth of the ordinary and the nickel-chromium irons may be considerably reduced by pretreatment.

A number of specimens were examined microscopically before and after test, with the object of noting any structural changes produced and of elucidating some effects observed during the tests. Longitudinal sections were cut from the $1\frac{1}{4}$ in. dia. cast bars in the condition as-received, and from the creep and growth test-pieces. In the condition as-received, therefore, it was usually possible to

examine the structure from the outside of the bar to the centre. As, however, the creep and growth test-pieces were machined from half-sections of the bars, the examination after test was confined to material taken from about half-way between the outside and centre of the original $1\frac{1}{4}$ in. dia. bars. Except where otherwise stated, the etching reagent used was 4% nitric acid in alcohol.

The results of the creep and growth tests, and of the micro-

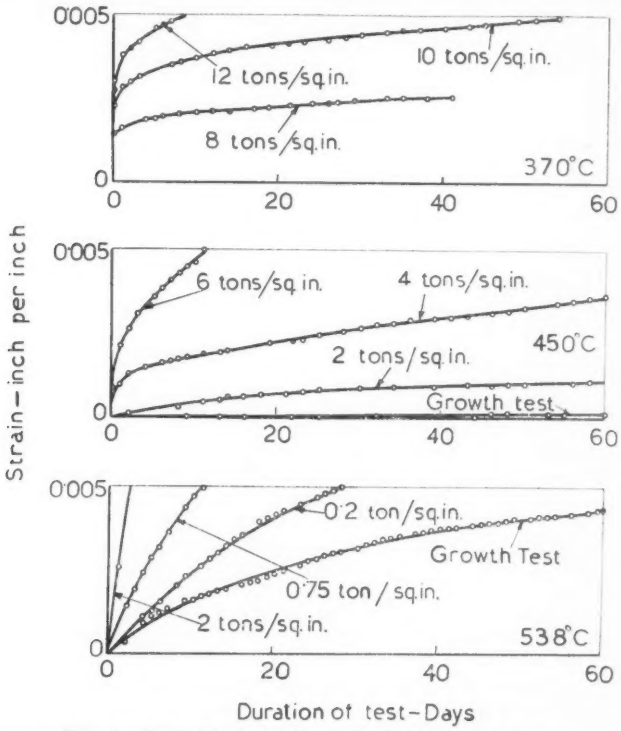


FIG. 1.—Strain/Duration Curves for Ordinary Cast Iron.

scopical examination, are discussed below under separate headings for each iron.

Ordinary Cast Iron.—Strain/duration curves for strains up to 0·005 in. per in. obtained in creep and growth tests on the ordinary cast iron are shown in Fig. 1. In this and subsequent figures showing creep curves the plotted strain includes both creep and such elastic deformation as may exist, and also growth.

Fig. 2 shows the relations between the stress and log. rate-of-strain at 40 days at the test temperatures. The rates of growth at 40 days are indicated by points along the axis of log. rate-of-strain. Growth tests were not made at 370° C. (700° F.). At 450° C. (842° F.) the rate of growth is small, but a very considerable increase occurs at 538° C. (1000° F.). At both temperatures growth determines the minimum rate of deformation, and thereby defines the trend of the curves of Fig. 2 to zero stress.

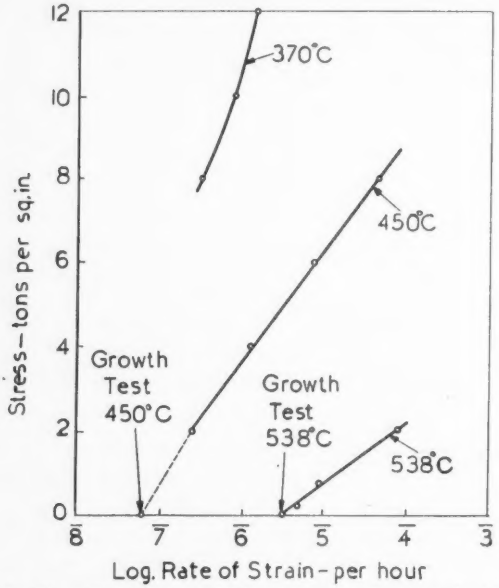


FIG. 2.—Stress/Log. Rate-of-Strain Curves for Ordinary Cast Iron.

The numerical results of the creep and growth tests are given in Table V., which contains data concerning the time to fracture and elongation at fracture (final strain) of the most highly stressed specimens. There is an indication that the elongation at fracture increases somewhat with increase in the time required to produce fracture.

Measurements show that growth is continuous at 450° C. and 538° C., and has not ceased in 130 days and 66 days at the respective temperatures. The magnitude of the growth is such as to preclude the use of the iron (as-cast) at such temperatures if deformation of any kind has to be severely limited. It was considered probable

that the growth could be considerably reduced by prior heat treatment; the tests described later, using the ordinary and the nickel-chromium irons, show that an improvement can be effected by heat treatment.

The structure of the cast iron, which was found to be uniform across the section, is illustrated in Figs. 13 to 18 (Plate XXIII.). It

TABLE V.—*Results of Creep and Growth Tests on Ordinary Cast Iron.*

Temperature of Test. °C.	Stress Applied. Tons per sq. in.	Duration of Test. (B = Broken, U = Unbroken.) Days.	Final Strain at Fracture or at End of Test % (On 2 in.).	Rate of Strain, Minimum or at 40 Days. In. per in. per hr.
370	12	40 U	$0{\cdot}63_5$	$0{\cdot}0000014_5$
,,	10	55 U	0·49	$0{\cdot}0000008_3$
,,	8	41 U	0·25	$0{\cdot}0000003_3$
450	8	9 B	2·5	0·0000458
,,	6	89 B	3·25	0·0000075
,,	4	93 U	0·44	$0{\cdot}0000012_9$
,,	2	83 U	$0{\cdot}12_8$	$0{\cdot}0000002_5$
,,	Growth test	130	0·02	$0{\cdot}0000000_6$
538	4	$1\frac{1}{4}$ B	3·0	...
,,	2	16–17 B	4·0	0·0000775
,,	0·75	58 U	3·0	$0{\cdot}0000091_7$
,,	0·2	41 U	1·14	0·0000050
,,	Growth test	66	0·91	$0{\cdot}0000032_9$

will be noted from Figs. 13 and 14, depicting the structure of the iron as-received, that the size and distribution of the graphite flakes are more or less normal, whilst the background is completely pearlitic, as would be expected from the high combined carbon content. The structure in Figs. 15 and 16 shows the effect produced by creep under a stress of 2 tons per sq. in. for 16–17 days at 538° C. There is little evidence of cracking, but the pearlite has very largely broken down, and the resulting graphite has been deposited on the existing flakes or as a very finely divided precipitate in the ferrite. A rather more advanced stage of decomposition is illustrated in Figs. 17 and 18, representing the structure of the growth test-piece after 66 days at 538° C. From these and other similar results, it appeared that the structural changes occurring during the tests depend upon the time of exposure rather than upon the magnitude of the stress.

Specimens were examined after creep for 89 days and growth for 130 days at 450° C., but no appreciable difference from the original condition was noted. Specimens tested at 370° C. were, therefore, not examined.

Nickel-Chromium Cast Iron.—Strain/duration curves for the nickel-chromium irons are shown in Fig. 3, and the stress/log. rate-of-strain relations are given in Fig. 4. Table VI. gives the numerical results of the tests.

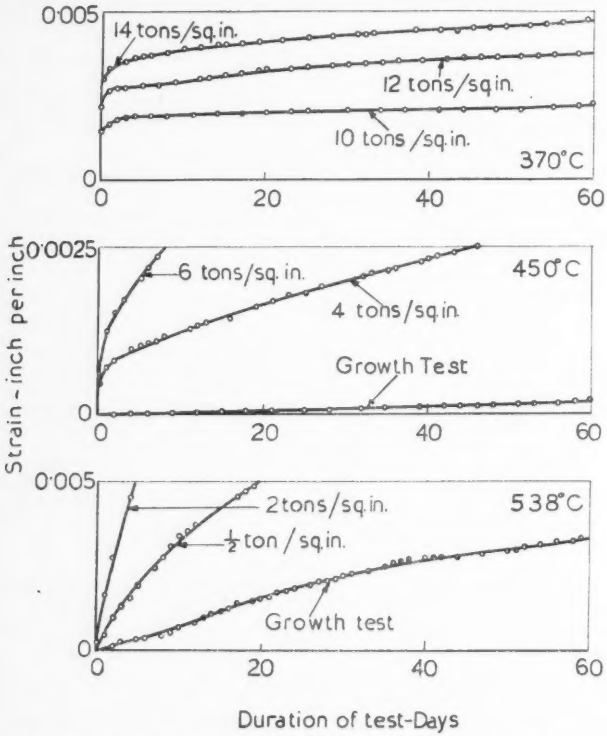


FIG. 3.—Strain/Duration Curves for Nickel-Chromium Cast Iron.

The rate of growth at 450° C. is somewhat greater for this iron than for the ordinary cast iron, with the result that the deformations of the two irons under stresses up to 2 or 3 tons per sq. in. are similar. The nickel-chromium iron is somewhat superior to the ordinary iron at 538° C., but its rate of growth at both 450° C. and 538° C. is such as to exclude material in the as-cast condition from service at those temperatures. It is shown later that a considerable improvement of the nickel-chromium iron as regards resistance both to creep and to growth can be effected by heat treatment.

The results plotted in Fig. 4, of the creep tests at 370° C., suggest that the iron will withstand a stress of a few tons per sq. in. without serious deformation.

The structure of this iron, as revealed by very light etching, is shown in Fig. 19 (Plate XXIV.) at a fairly high magnification. This is reproduced particularly to show the unusual fringes of graphite

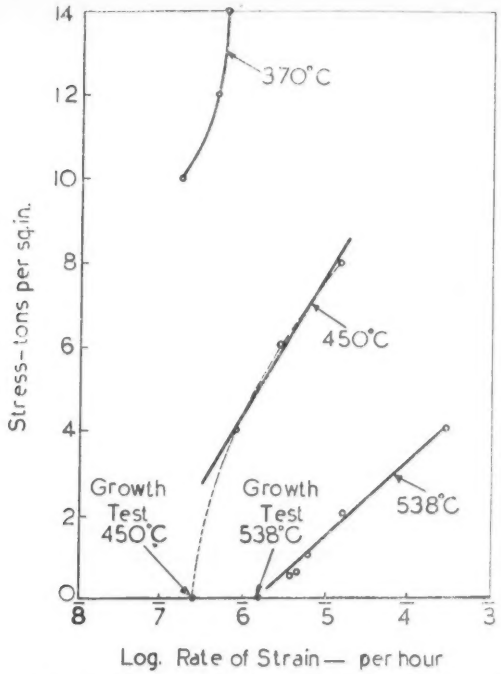


FIG. 4.—Stress/Log. Rate-of-Strain Curves for Nickel-Chromium Cast Iron.

TABLE VI.—*Results of Creep and Growth Tests on Nickel-Chromium Cast Iron.*

Temperature of Test. ° C.	Stress Applied. Tons per sq. in.	Duration of Test. (B = Broken, U = Unbroken.) Days.	Final Strain at Fracture or at End of Test. % (On 2 in.).	Rate of Strain, Minimum or at 40 Days. In. per in. per hr.
370	14	81 U	0·49	$0{\cdot}0000005_7$
,,	12	84 U	0·41	$0{\cdot}0000004_5$
,,	10	62 U	0·23	$0{\cdot}0000001_7$
450	8	11–12 B	1·0	0·0000142
,,	6	81 U	0·87	$0{\cdot}0000027_1$
,,	4	91 U	$0{\cdot}36_5$	$0{\cdot}0000007_9$
,,	Growth test	89	0·06	$0{\cdot}0000002_4$
538	4	2 B	2·0	...
,,	2	77 U	3·92	0·0000158
,,	1	77 U	1·31	$0{\cdot}0000061_7$
,,	0·625	69 U	1·04	0·0000045
,,	0·5	37 U	0·70	$0{\cdot}0000037_5$
,,	Growth test	78	0·37	$0{\cdot}0000014_6$

which were noticed close to and parallel to the main graphite flakes in certain sections examined. The more generally observed type of structure may be seen in Figs. 20 and 21, which represent the actual structure after creep at 4 tons per sq. in. for 2 days at 538° C. The graphite flakes are uniform and not too large, whilst the distribution of graphite and phosphide eutectic appears to be

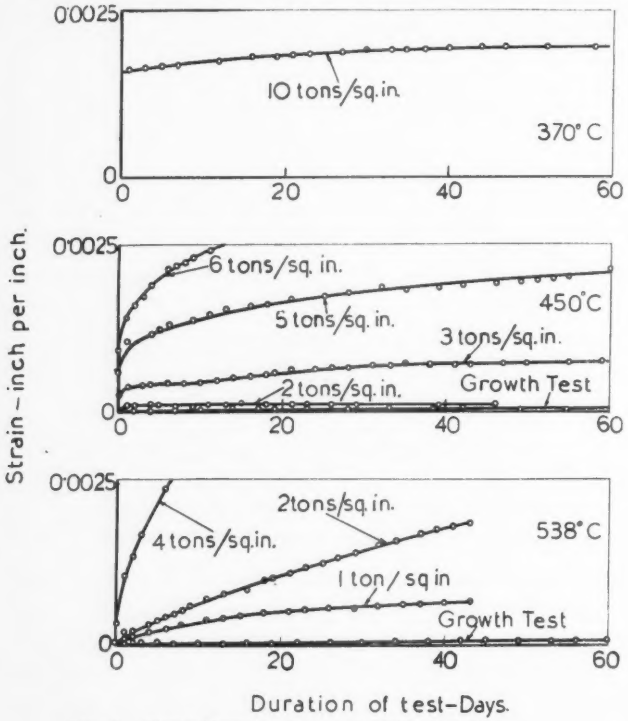


FIG. 5.—Strain/Duration Curves for Silal Cast Iron.

regular throughout. As in the ordinary iron, the background is pearlitic. Further creep specimens which have been subjected to test at 538° C. for more prolonged periods were not examined, as it was considered that any resulting changes in microstructure would be shown equally in the more prolonged growth tests. The structure observed in the growth specimen after 78 days at 538° C. is illustrated in Figs. 22 and 23. The former, which was etched lightly, shows the more usual type of graphite, and indicates that, although there has been a tendency for the cementite to spheroidise, only

slight decomposition into graphite, &c., appears to have taken place. As shown in Fig. 23, however, a number of transverse and longitudinal fissures, for the most part rectilinear, are to be seen in certain places, which correspond frequently with the appearance of "fringed" graphite. It was, therefore, thought at first that this "fringed" graphite was a sign of incipient oxidation and general break-up of the material. The fact that, as shown in Fig. 19, "fringed" graphite is sometimes found in this iron in the as-received condition appears, however, to contradict this suggestion and point to its formation as being due to a decomposition of the austenite during cooling after casting. It should be noted that

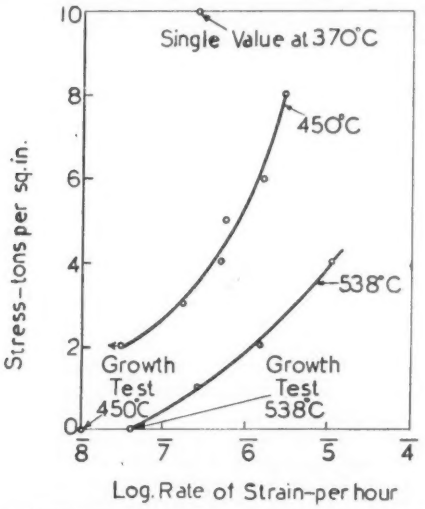


FIG. 6.—Stress/Log. Rate-of-Strain Curves for Silal Cast Iron.

this iron contains about 2% of silicon which has probably been added to counteract the effect of the chromium, which might otherwise cause the formation of an undue proportion of carbide.

Silal Cast Iron.—Although the growth of Silal cast iron at 450° C. and 538° C. was discernible, it was very small in amount and not accurately measurable. The deformations in the creep tests may, therefore, be taken to represent true creep strain, the microscopical evidence of structural change, as described later, being such as to indicate that growth was not likely to be appreciably influenced by the applied stress.

Fig. 5 shows the strain/duration curves obtained, and Fig. 6 the relations between the stress and the log. rate-of-strain. The numerical results of the tests are given in Table VII.

TABLE VII.—*Results of Creep and Growth Tests on Silal Cast Iron.*

Temperature of Test. ° C.	Stress Applied. Tons per sq. in.	Duration of Test. (B = Broken, U = Unbroken.) Days.	Final Strain at Fracture or at End of Test. % (On 2 in.).	Rate of Strain, Minimum or at 40 Days. In. per in. per hr.
370	14	8 B	0·5	...
,,	10	94 U	$0{\cdot}19_5$	$0{\cdot}0000002_5$
450	8	2 B	0·5	$0{\cdot}0000028_2$
,,	6	42 B	0·5	$0{\cdot}0000015_8$
,,	5	248 U	0·45	$0{\cdot}0000005_6$
,,	4	309 B	0·5	0·0000005
,,	3	171 U	$0{\cdot}09_8$	$0{\cdot}0000001_7$
,,	2	46 U	$0{\cdot}00_8$	$<0{\cdot}0000000_3$
,,	Growth test	114	$0{\cdot}00_{25}$	$<0{\cdot}0000000_1$
538	4	33 B	1·25	0·0000104
,,	2	43 U	0·18	$0{\cdot}0000014_6$
,,	1	43 U	$0{\cdot}06_3$	$0{\cdot}0000002_5$
,,	Growth test	62	$0{\cdot}00_{75}$	$<0{\cdot}0000000_4$

The Silal cast iron is definitely superior to the ordinary and nickel-chromium cast irons. The rate of strain at 370° C. for a stress of 10 tons per sq. in. (*see* Fig. 6), and the further creep test results at 450° C. and 538° C. demonstrate the load-carrying possibilities of the iron. At 450° C., for example, a stress of 4 tons per sq. in. produces a creep rate at 40 days of 5×10^{-7} in. per in. per hr., and the material supports this stress for 309 days before fracture ensues, but at 2 tons per sq. in. the creep rate is only about one-twentieth of that at 4 tons per sq. in.

The structure near the outside of the bars as-received is reproduced in the unetched and etched states in Figs. 24 and 25 (Plates XXIV. and XXV.). The dendritic structure is clearly visible. The graphite is small and largely of the supercooled type, and there is no pearlite present. In comparison, Fig. 26 shows the structure near the centre of the bar where the graphite flakes are small, but where the supercooled type of graphite is not so conspicuous. It will thus be seen that the structure of the Silal bars is not as uniform as that of the two previous irons. Fig. 27 represents the same structure at higher magnification and shows the appearance of the phosphide eutectic. In certain places near the centre of the bar a trace of an unusual structure, possibly of a further constituent, is found within the ferrite grains. The structure in the ferrite is more clearly developed after prolonged treatment at 450° C., as is shown in Figs. 28 and 29, after creep and growth tests for 43 days and 114 days respectively. There is a tendency for the constituent in the ferrite to break up after a time, and this is more noticeable in tests at 538° C. Apart from the behaviour of the ferrite, there appears to be little general structural change during treatment at 450° C. or at 538° C.

Nicrosilal Cast Iron.—The structure of the first batch of this iron

was found to be somewhat variable. Figs. 30 and 31 (Plates XXV. and XXVI.) show the structure revealed by light etching of one bar, whilst Figs. 32 and 33 show that near one end of another bar. Examination of further sections indicated that the structure shown in Figs. 30 and 31 is typical of the whole bar. Figs. 32 and 33, however, represent only one part of the second bar, the remainder exhibiting larger graphite flakes than those depicted for the first bar. It thus appears that the composition is critical, in that very slight changes either in the composition or the conditions of casting may cause considerable differences in structure. Whatever the type of graphite, the iron consists mainly of austenite, which is only slightly etched after immersion in a 12% solution of nitric acid in alcohol for 1 min. A second light-etching constituent is also present in small amounts. This constituent has not been identified,

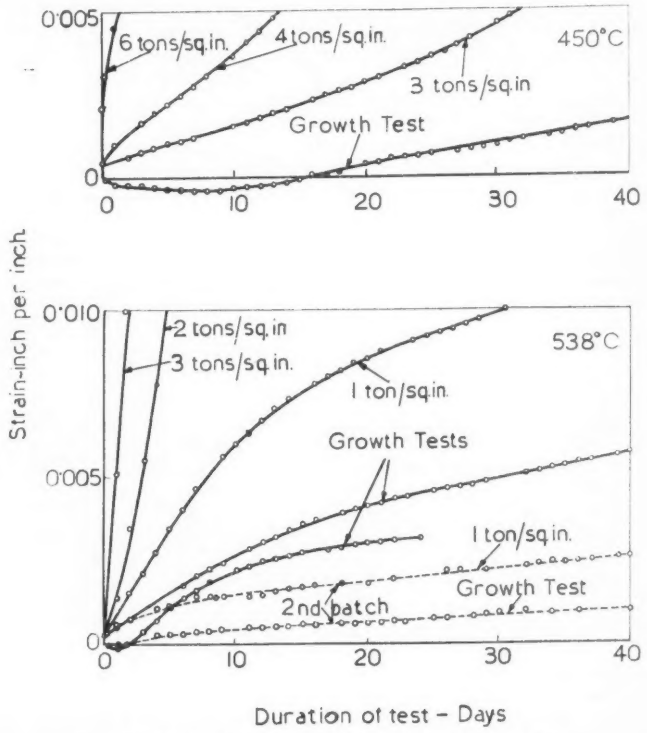


FIG. 7.—Strain/Duration Curves for Nicrosilal Cast Iron.

but it appears likely to be related to the phosphorus content and takes up an interdendritic position.

Creep and growth tests were made at 450° C. and 538° C. on the first batch of Nicrosilal cast iron. The strain/duration curves

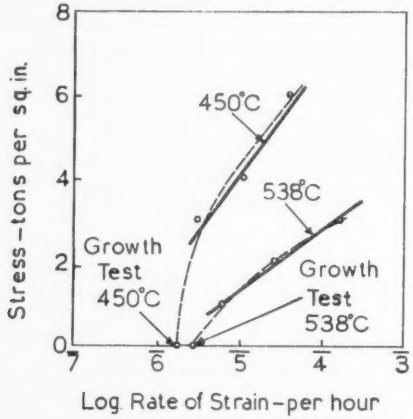


FIG. 8.—Stress/Log. Rate-of-Strain Curves for Nicrosilal Cast Iron.

obtained are shown in Fig. 7, and the corresponding stress/log. rate-of-strain curves in Fig. 8. Table VIII. contains the numerical results of the tests. At 450° C. the sample of Nicrosilal cast iron examined is inferior to the ordinary cast iron, and at 538° C. is very

TABLE VIII.—*Results of Creep and Growth Tests on Nicrosilal Cast Iron (1st Batch).*

Temperature of Test. ° C.	Stress Applied. Tons per sq. in.	Duration of Test. (B = Broken, U = Unbroken.) Days.	Final Strain at Fracture or at End of Test. % (On 2 in.).	Rate of Strain, Minimum or at 40 Days. In. per in. per hr.
450	6	38 B	8·0	0·0000417
,,	4	20 U	0·78	0·0000117
,,	3	40 U	0·69	$0{\cdot}0000031_2$
,,	Growth test	44	$0{\cdot}16_2$	$0{\cdot}0000018_3$
538	3	18 B	11·0	0·0001710
,,	2	41 U	4·42	0·0000271
,,	1	40 U	1·07	$0{\cdot}0000062_5$
,,	Growth test	43	0·58	$0{\cdot}0000028_1$

similar to the nickel-chromium cast iron. Its growth is very much greater than that of the Silal cast iron.

At 538° C. the strain/duration curves of the Nicrosilal iron have a somewhat unusual character, mainly demonstrated in

Fig. 7 by the growth curve and the curve for a stress of 1 ton per sq. in. The curves show that a fairly steady rate of strain occurs for several days, followed by a rapidly decreasing rate and then by comparatively little change in rate. It was found that the Brinell hardness of the creep and growth specimens varied from a value of about 135 before the test to about 430 after 40 days at 538° C. A growth specimen maintained at 450° C. for 44 days also showed considerable hardening, which varied from one end of the specimen to the other, thus confirming that the original bar was not uniform along the length. These unusual characteristics suggested that changes were taking place in the iron during test, and these have been studied microscopically. Figs. 34 and 35 show the structure of a specimen after creep test at 3 tons per sq. in. for 18 days at 538° C. The specimen was etched in a 4% solution of nitric acid in alcohol for about 10 sec. The austenite has very largely broken down to a dark-etching sorbite, and, as would be expected, the material was no longer non-magnetic. The same type of breakdown occurred at 450° C., but the process was considerably slower than at 538° C.

The structure of the creep specimen suggests that the original austenite grains were cored, and it was thought that this lack of uniformity in composition might be related to the comparatively rapid breakdown. In order to test this, a number of samples from the bar illustrated in Figs. 30 and 31 were annealed for 3½ hr. at 1080° C. This treatment was found to effect considerable diffusion of the interdendritic constituent, and gave greater uniformity to the austenite. These specimens were then maintained at 538° C., together with specimens from the same bar which were not annealed at 1080° C. Specimens were examined after 3 days (Figs. 36 and 37, Plates XXVI. and XXVII.), 6 days (Figs. 38 and 39), and 24 days (Figs. 40 and 41). It is found that in the unannealed samples, austenite breakdown occurs in areas which have a direct relationship to the original dendritic structure, whereas in the annealed samples breakdown occurs rather less rapidly, starting from comparatively few centres and spreading gradually through the material. These changes are also shown by the following Brinell hardness values:

Time held at 538° C.	Brinell Hardness No.	
Days.	As-Received.	Annealed.
0	135	135
3	265	157
6	333	260
24	431	430

The hardness numbers are the mean of several, and were obtained with a 1-mm. ball and load of 30 kg. Owing to variation across the section, the values given above must be taken as representing the general trend of hardness changes and not as absolute values.

The opinion was expressed that although the particular iron investigated was suitable for severe service conditions at tempera-

tures above about 800° C., the composition was probably critical as regards stability of structure at 538° C. A fresh batch of slightly different composition was, therefore, obtained (*see* Table I.), and tested for creep and growth at 538° C. The results obtained are shown by the dotted curves in Fig. 7, which disclose that the second batch of Nicrosilal iron was somewhat superior to the first. However, hardening was still found to take place during the creep test at 538° C., the Brinell hardness being 160 before test and 320 after test. In addition, microscopical examination revealed that

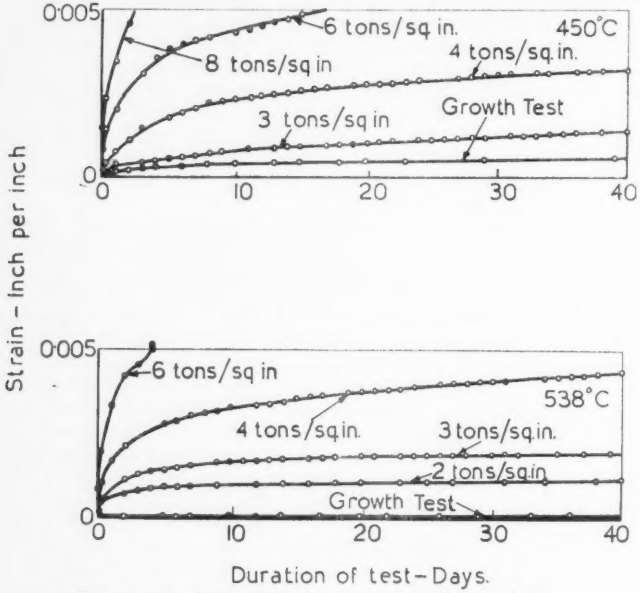


FIG. 9.—Strain/Duration Curves for Niresist Cast Iron.

the same structural breakdown occurred, though less rapidly than in the case of the first batch of the iron. This may be seen in Figs. 42 and 43 (Plates XXVII. and XXVIII.), illustrating the effect of exposure at 538° C. for 40 days under a stress of 1 ton per sq. in.

Niresist Cast Iron.—The strain/duration curves obtained in creep and growth tests at 450° C. and 538° C. on the Niresist cast iron are shown in Fig. 9, and the corresponding stress/log. rate-of-strain curves are shown in Fig. 10. The numerical results of the tests are given in Table IX.

The growth of this iron at 450° C. was found to exceed that at 538° C., and for that reason the curve in Fig. 10 for the tests at

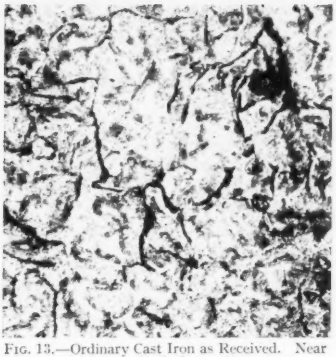


FIG. 13.—Ordinary Cast Iron as Received. Near centre. Etched. × 150.

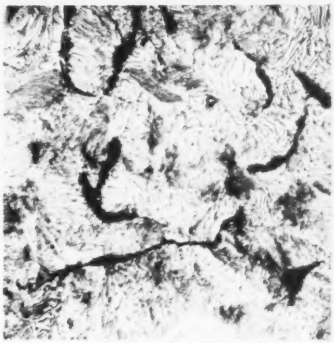


FIG. 14.—Ordinary Cast Iron as Received. Etched. × 500.

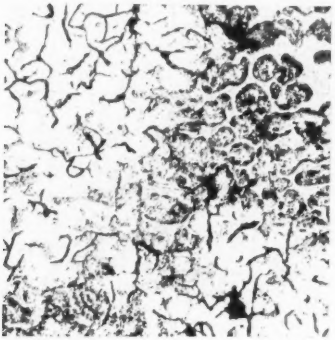


FIG. 15.—Ordinary Cast Iron. Creep, 2 tons per sq. in.; 16-17 days (broke) at 538° C. Etched. × 150.

FIG. 16.—Ordinary Cast Iron. Creep, 2 tons per sq. in.; 16-17 days (broke) at 538° C. Etched. × 500.

FIG. 17.—Ordinary Cast Iron. Growth, 66 days at 538° C. Etched. × 150.

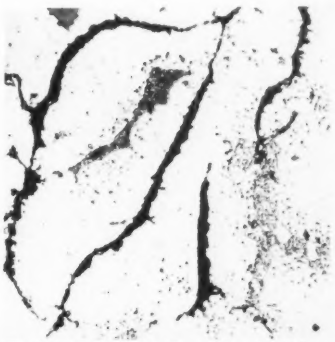


FIG. 18.—Ordinary Cast Iron. Growth, 66 days at 538° C. Etched. × 500.

(Micrographs reduced to two-thirds linear in reproduction.)

[*Tapsell, Becker, and Conway.*

[*To face p.* 320 P.

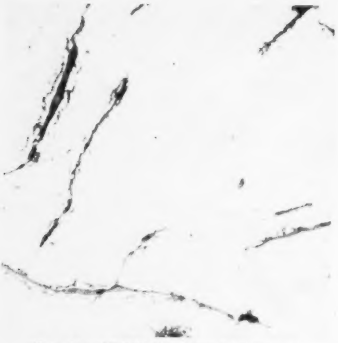


FIG. 19.—Nickel-Chromium Cast Iron as Received. Lightly etched. × 500.

FIG. 20.—Nickel-Chromium Cast Iron. Creep, 4 tons per sq. in.; 2 days (broke) at 538° C. Etched. × 150.

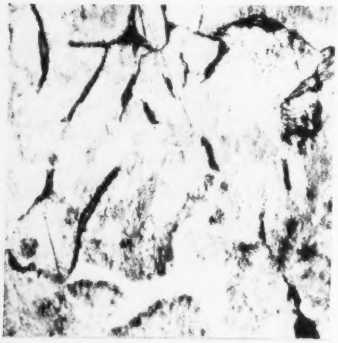


FIG. 21.—Nickel-Chromium Cast Iron. Creep, 4 tons per sq. in.; 2 days (broke) at 538° C. Etched. × 500.

FIG. 22.—Nickel-Chromium Cast Iron. Growth, 78 days at 538° C. Lightly etched. × 500.

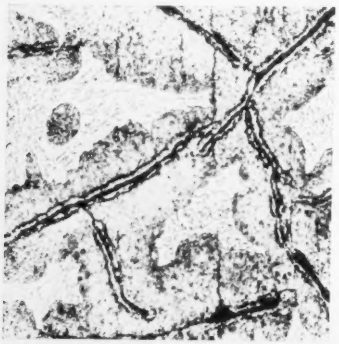


FIG. 23.—Nickel-Chromium Cast Iron. Growth, 78 days at 538° C. Showing graphite fringes. Etched. × 500.

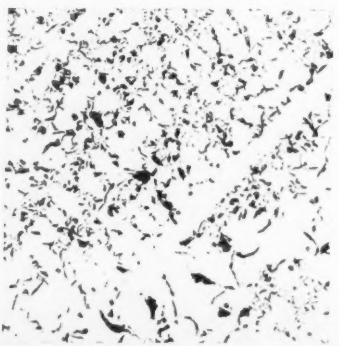


FIG. 24.—Silal as Received. Near edge. Unetched. × 150.

(Micrographs reduced to two-thirds linear in reproduction.)

[Tapsell, Becker, and Conway.

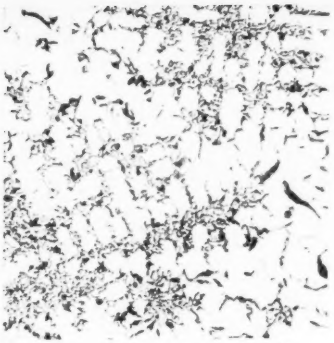


FIG. 25.—Silal as Received. Near edge. Etched. × 150.

FIG. 26.—Silal as Received. Near centre. Etched. × 150.

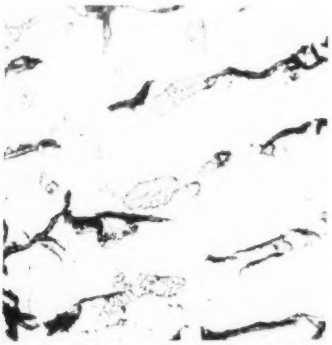


FIG. 27.—Silal as Received, showing phosphide eutectic. Etched. × 500.

FIG. 28.—Silal. Creep, 6 tons per sq. in.; 43 days at 450° C. Etched. × 500.

FIG. 29.—Silal. Growth, 114 days at 450° C. Etched. × 500.

FIG. 30.—Nicrosilal as Received. Slightly etched. × 150.

(Micrographs reduced to two-thirds linear in reproduction.)

[*Tapsell, Becker, and Conway.*

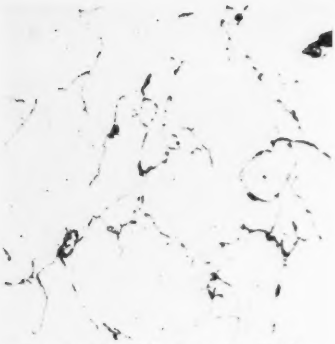


FIG. 31.—Nicrosilal as Received. Slightly etched. × 500.

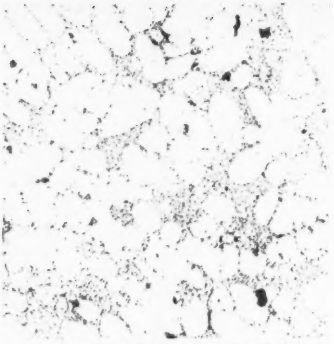


FIG. 32.—Nicrosilal as Received. Slightly etched. × 150.

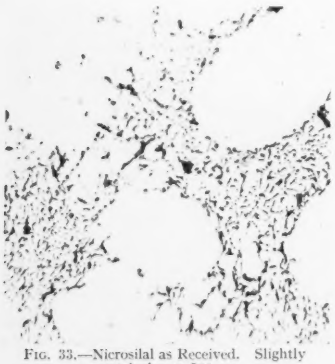


FIG. 33.—Nicrosilal as Received. Slightly etched. × 500.

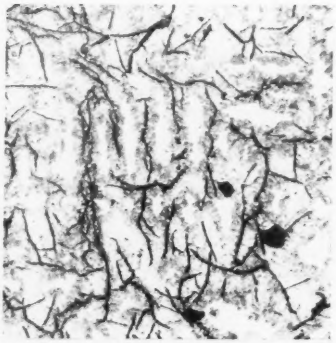


FIG. 34.—Nicrosilal. Creep, 3 tons per sq. in.; 18 days (broke) at 538° C. Etched. × 150.

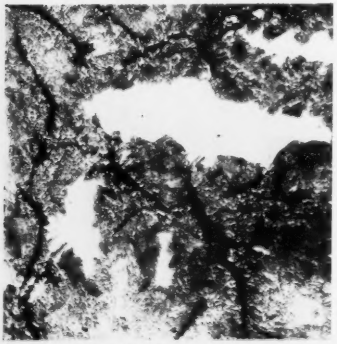


FIG. 35.—Nicrosilal. Creep, 3 tons per sq. in.; 18 days (broke) at 538° C. Etched. × 500.

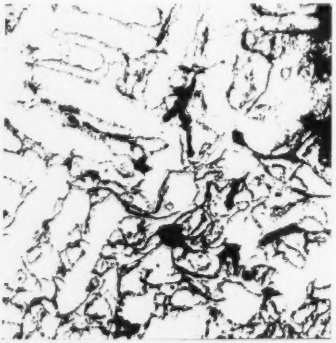


FIG. 36.—Nicrosilal as Received, followed by 3 days at 538° C. Etched. × 150.

(Micrographs reduced to two-thirds linear in reproduction.)

[*Tapsell, Becker, and Conway.*

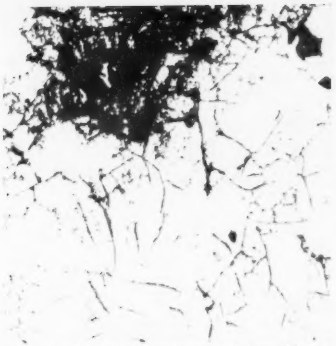


FIG. 37.—Nicrosilal, heat-treated, followed by 3 days at 538° C. Etched. × 150.

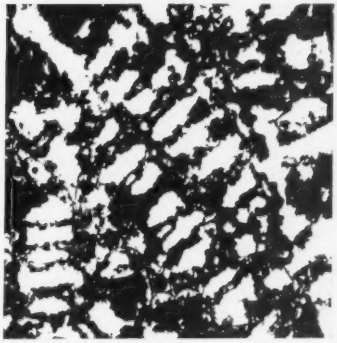


FIG. 38.—Nicrosilal as Received, followed by 6 days at 538° C. Etched. × 150.

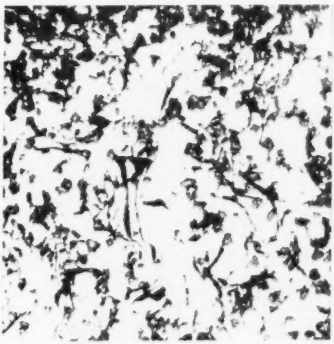


FIG. 39.—Nicrosilal, heat-treated, followed by 6 days at 538° C. Etched. × 150.

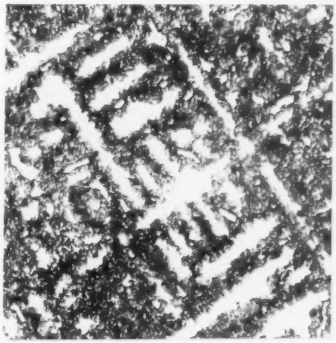


FIG. 40.—Nicrosilal as Received, followed by 24 days at 538° C. Etched. × 150.

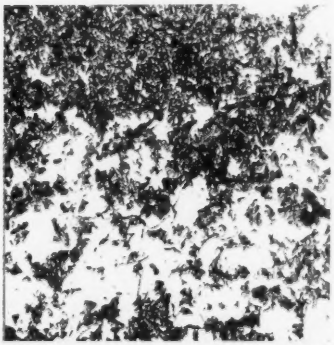


FIG. 41.—Nicrosilal, heat-treated, followed by 24 days at 538° C. Etched. × 150.

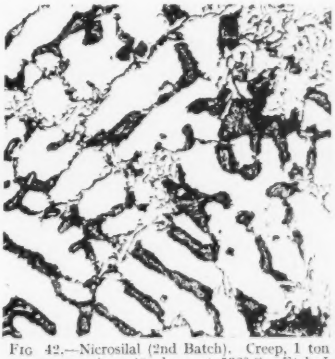


FIG. 42.—Nicrosilal (2nd Batch). Creep, 1 ton per sq. in.; 40 days at 538° C. Etched. × 150.

(Micrographs reduced to two-thirds linear in reproduction.)

[*Tapsell, Becker, and Conway.*

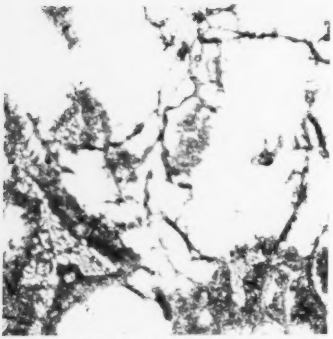


FIG. 43.—Nicrosilal (2nd Batch). Creep, 1 ton per sq. in.; 40 days at 538° C. Etched. × 500.

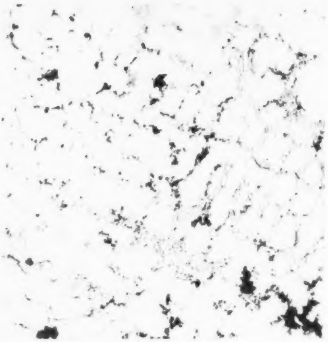


FIG. 44.—Niresist as Received. Etched. × 150.

FIG. 45.—Niresist as Received. Etched. × 500.

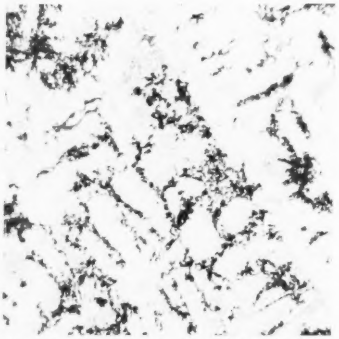


FIG. 46.—Niresist. Growth specimen; 56 days at 450° C. Etched. × 150.

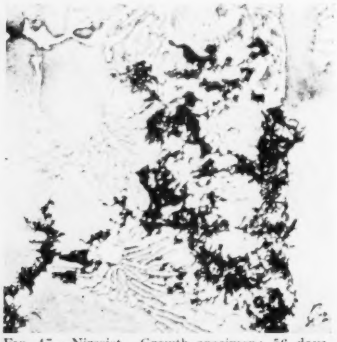


FIG. 47.—Niresist. Growth specimen; 56 days at 450° C. Etched. × 500.

FIG. 48.—Ordinary Cast Iron after 5 days at 650° C. Etched. × 500.

(Micrographs reduced to two-thirds linear in reproduction.)

[*Tapsell, Becker, and Conway.*

FIG. 49.—Nickel-Chromium Iron after 5 days at 650° C. Etched. × 500.

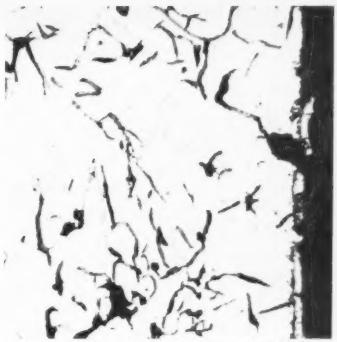


FIG. 50.—Silal. Growth specimen after 15 days at 850° C. Section adjacent to surface of specimen. Etched. × 150.

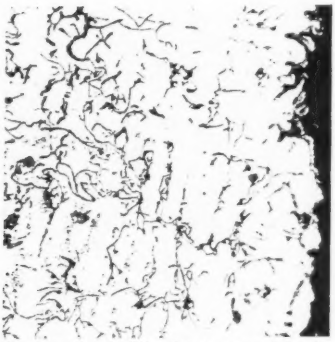


FIG. 51.—Nicrosilal (1st Batch). Growth specimen; 40 days at 850° C. Section adjacent to surface of specimen. Etched. × 150.

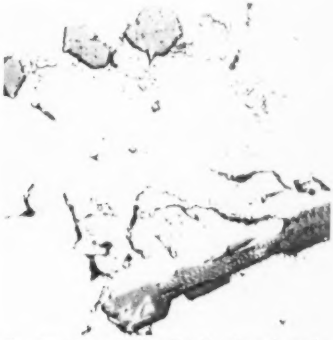


FIG. 52.—Nicrosilal (1st Batch). Growth specimen; 40 days at 850° C. Etched. × 500.

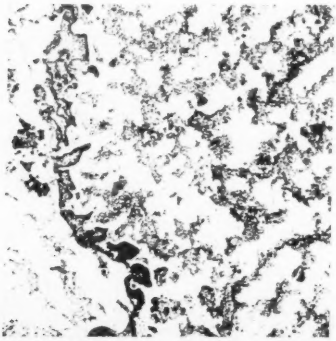


FIG. 53.—Niresist. Growth specimen; 42 days at 850° C. Part of oxidised skin and adjacent metal, showing thin reddish intermediate zone. Etched. × 150.

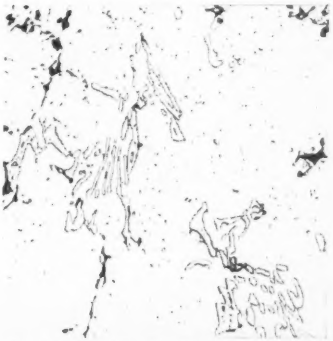


FIG. 54.—Niresist. Growth specimen; 42 days at 850° C. Body of cast iron, showing constituent in the austenite. Etched. × 500.

(Micrographs reduced to two-thirds linear in reproduction.)

[*Tapsell, Becker, and Conway.*

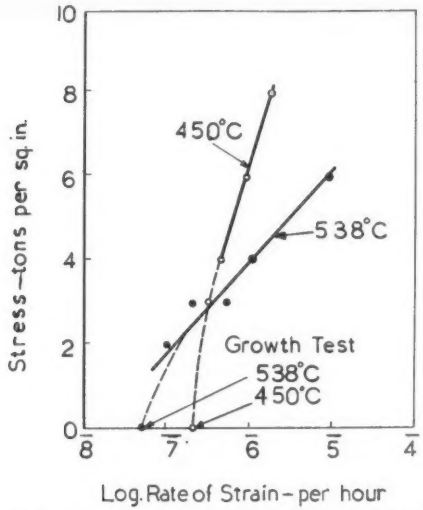


FIG. 10.—Stress/Log. Rate-of-Strain Curves for Niresist Cast Iron.

450° C. crosses that for the tests at 538° C. The rate of strain under a stress of about 3 tons per sq. in. is the same at both temperatures, but at lower stresses the rate of strain would be greater at 450° C. than at 538° C. The Niresist cast iron has the best resistance to creep and growth at 538° C. of the irons tested, but at 450° C. the Silal iron, by virtue of its very low growth, is superior to the Niresist iron.

TABLE IX.—*Results of Creep and Growth Tests on Niresist Cast Iron.*

Temperature of Test. ° C.	Stress Applied. Tons per sq. in.	Duration of Test. (B = Broken, U = Unbroken.) Days.	Final Strain at Fracture or at End of Test. % (On 2 in.).	Rate of Strain, Minimum or at 40 Days. In. per in. per hr.
450	8	42 U	1·04	$0{\cdot}0000018_7$
,,	6	40 U	0·57	$0{\cdot}0000009_2$
,,	4	40 U	0·32	$0{\cdot}0000004_8$
,,	3	44 U	$0{\cdot}13_7$	$0{\cdot}0000003_3$
,,	Growth test	56	$0{\cdot}06_3$	$0{\cdot}0000002_1$
538	6	6 B	1·5	$0{\cdot}0000095_8$
,,	4	42 U	0·44	$0{\cdot}0000010_4$
,,	3	40 U	$0{\cdot}19_5$	$0{\cdot}0000002_1$
,,	3 (repeat)	40 U	0·32	$0{\cdot}0000005_2$
,,	2	40 U	$0{\cdot}11_5$	0·0000001
,,	Growth test	41	0·01	$0{\cdot}0000000_5$

Figs. 44 and 45 show the structure of the Niresist cast iron, which, like Nicrosilal, is austenitic. The polished specimen, however, is very much more easily etched than that of Nicrosilal, and the austenite contains quite a large proportion of a light-etching constituent which appears as a eutectic.

A creep specimen which had been stressed at 6 tons per sq. in. for 6 days at 538° C. exhibited a structure almost identical with that of the original material, and even after 41 days in the growth test the only obvious change was that due to the precipitation of additional graphite around the eutectic areas, as referred to below. In view of the fact that Niresist has less resistance to creep and growth at 450° C. than at 538° C. it was thought that the austenite might be less stable at 450° C. Microscopic examination of a growth specimen after 56 days at 450° C. (Figs. 46 and 47), however, showed that the austenite had not decomposed. In addition, the growth specimens were found to remain non-magnetic, and it is clear, therefore, that at 538° C. and at 450° C. the stability of the austenite in Niresist is much greater than that in Nicrosilal.

Considerable graphitisation occurred during tests at 538° C. and 450° C., the effect upon the microstructure being revealed by comparing Figs. 46 and 47 with Figs. 44 and 45. In order to obtain quantitative information, millings were taken from the growth specimens, their carbon contents being compared below with those for the iron in the condition as cast :

		After Growth for—	
	As Cast.	56 days at 450° C.	41 days at 538° C.
Total carbon, %	2·44	2·45	2·36
Graphitic carbon, %	1·70	2·14	2·20
Combined carbon, % (by difference)	0·74	0·31	0·16

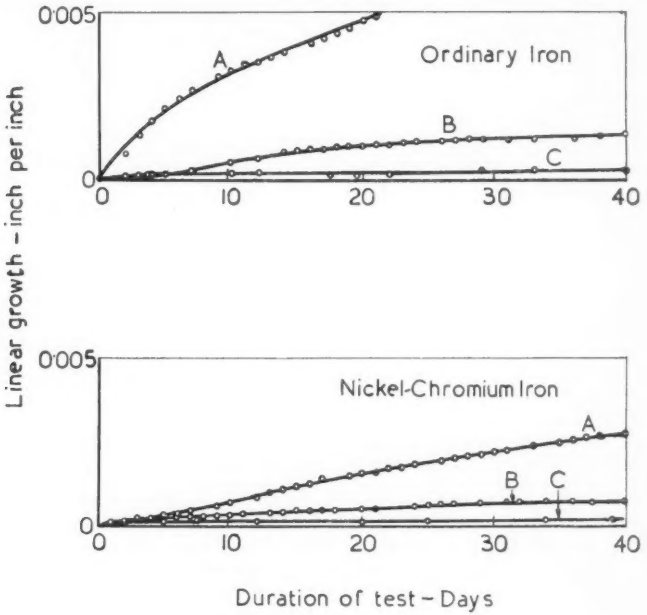
Within the limits of accuracy of these determinations, it may be concluded that graphitisation has proceeded further in 41 days at 538° C. than in 56 days at 450° C. Although it cannot be assumed that the figures for combined carbon represent equilibrium values for the particular temperatures, there is evidence that the stable condition is reached more rapidly at 538° C. than at 450° C., and it is possible that this may have some bearing on the unusual relationship of both the growth and the creep properties at the two temperatures.

Effect of Heat Treatment on the Properties of Ordinary and Nickel-Chromium Cast Irons.

The growth of the ordinary and nickel-chromium cast irons in the as-cast condition is too great between 450° and 538° C. to warrant their use in steam-plant components where distortion of appreciable magnitude is not permissible. For certain reasons, based on the shape of the growth curves and the knowledge that much of the growth may be accounted for by the graphitisation of

the pearlite, it was considered possible that a heat treatment at a temperature higher than 538° C. might carry the irons over the early stages of growth and result in a reduction of the growth in subsequent heating at 538° C.

Preliminary tests were carried out on both irons to determine the period of annealing required to effect the structural changes. Specimens were examined microscopically after 2 days and 5 days at 600° C. and after 1 day and 5 days at 650° C. It was found that the ordinary iron responded to treatment much more readily than did the nickel-chromium iron. In 2 days at 600° C., the ordinary iron showed definite signs of change, whilst after 5 days most of the pearlite had graphitised and that remaining had become spheroidised. In the same period the nickel-chromium iron had not been appreciably affected. At 650° C. the breakdown occurred more rapidly. For the ordinary iron 5 days sufficed to graphitise all the cementite, apart possibly from a certain amount associated

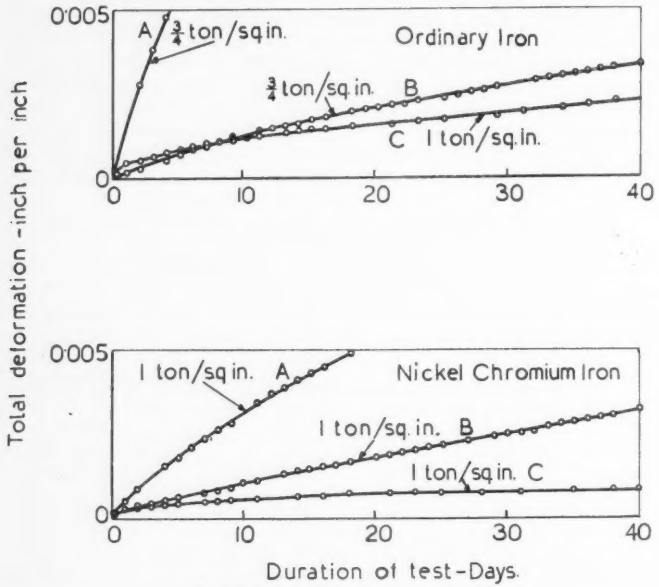


A as received.
B after 5 days at 600° C.
C after 5 days at 650° C.

FIG. 11.—Effect of Heat Treatment on Linear Growth of Cast Irons at 538° C.

with the phosphide eutectic, whilst for the nickel-chromium iron some of the cementite had been graphitised, although a considerable quantity remained in the spheroidised form. The structures after 5 days at 650° C. are illustrated in Figs. 48 and 49 (Plates XXVIII. and XXIX.).

For the actual growth and creep tests two specimens of each material were first heated at 600° C. for 5 days, the growth during



A as received.
B after 5 days' growth at 600° C.
C after 5 days' growth at 650° C.

FIG. 12.—Effect of Heat Treatment on Deformation under Tensile Stress of Cast Irons at 538° C.

heat treatment being measured. The average total growth of the ordinary iron specimens after 5 days was 0·0063 in. per in., and that of the nickel-chromium iron 0·0028 in. per in. The temperature was then lowered to 538° C., and one specimen of each iron was stressed to obtain a creep curve, and the other left unloaded to measure the growth. The beneficial results of the heat treatment are disclosed by the results given in Table X., and the curves shown in Figs. 11 and 12. Repeat tests at 538° C. were then made on fresh specimens after heat treatment at 650° C. for 5 days, the total growth at this temperature being 0·0086 in. per in. for the

ordinary iron, and 0·0027 in. per in. for the nickel-chromium iron. The further improvement effected by heat treatment at 650° C. is shown by the results in Table X. and the curves of Figs. 11 and 12.

TABLE X.—*Growth and Creep of Ordinary and Nickel-Chromium Cast Irons at 538° C. after Heat Treatment at 600° C. and 650° C.*

Material.	Condition.	Stress. Tons per sq. in.	Final Strain at 40 Days. %.	Rate of Strain at 40 Days. In. per in. per hr.
Ordinary cast iron.	As-received.	Growth test	0·73	0·00000329
	Heat-treated for 5 days at 600° C.	,,	$0·13_5$	0·00000050
	Heat-treated for 5 days at 650° C.	,,	$0·02_8$	0·00000004
	As-received.	$\frac{3}{4}$	2·01	0·00000916
	Heat-treated for 5 days at 600° C.	$\frac{3}{4}$	0·34	0·00000229
	Heat-treated for 5 days at 650° C.	1	$0·23_8$	0·00000167
Nickel-chromium cast iron.	As-received.	Growth test	0·27	0·00000146
	Heat-treated for 5 days at 600° C.	,,	0·07	0·00000025
	Heat-treated for 5 days at 650° C.	,,	$0·01_8$	0·00000008
	As-received.	1	0·86	0·00000617
	Heat-treated for 5 days at 600° C.	1	0·32	0·00000271
	Heat-treated for 5 days at 650° C.	1	$0·07_8$	0·00000017

To determine whether the pretreatment caused appreciable loss in strength of the irons at air temperature, specimens of the two irons, 0·45 in. in dia., were heat-treated at 650° C. for 5 days,

TABLE XI.—*Effect of Heat Treatment at 650° C. on the Tensile Properties at Air Temperature.*

Material.	Condition.	Ultimate Stress. Tons per sq. in.		Approximate Elongation on Gauge Length. $L = 4\sqrt{\text{Area}}$. %
		Individual Values.	Average Value.	
Ordinary iron.	Heat-treated for 5 days at 650° C.	9·8 10·3	10·0	0·5 0·5
	As-cast.	14·6 15·8 15·4	15·3	0·5 0·5 0·5
Nickel-chromium iron.	Heat-treated for 5 days at 650° C.	12·6 11·4	12·0	0·5 0·5
	As-cast.	14·3 12·3	13·3	0·5 0·5

machined to 0·35 in. dia., and then subjected to a tensile test at air temperature. The results of these tests are compared in Table XI. with the results obtained for the irons in the as-cast condition.

The heat treatment at 650° C. has produced a decided lowering of the strength of the ordinary iron, but has had far less effect in the case of the nickel-chromium iron. The results are in agreement with those of other investigators who have previously shown that such annealing treatments cause less reduction in tensile strength of cast irons containing chromium than of ordinary irons.

No tests have been made to determine the effect of heat treatment on the creep and growth at 450° C., but it is probable that such treatment would be as beneficial in its effect at 450° C. as at 538° C.

Comparative Behaviour of the High-Alloy Irons at 850° C.

In view of the fact that the Silal, Nicrosilal, and Niresist irons have been developed chiefly for use at relatively high temperatures, some comparative creep and growth tests have been made on these irons at 850° C. The creep and growth specimens used were each 0·30 in. in dia. and of 2 in. gauge length. The results of the tests are given in Table XII.

Table XII.—*Results of Comparative Tests at 850° C.*

Material.	Stress. Tons per sq. in.	Duration of Test. Days.	Final Strain. %.
			Linear growth
Silal cast iron . .	Growth test	15	2·52
Niresist cast iron . .	,,	42	0·33
Nicrosilal cast iron (1st batch) . . .	,,	41	0·05
			Elongation on 2 in. at fracture
Niresist cast iron . .	1	1·9 (Broken)	0·75
Nicrosilal cast iron (1st batch) . . .	1	4–5 (Broken)	1·0
Nicrosilal cast iron (2nd batch) . . .	1	13 (Broken)	1·5

It is evident that the Nicrosilal cast iron is superior to the other cast irons as regards growth at 850° C. Judging from the results of the tests at 1 ton per sq. in., the Nicrosilal iron appears to be definitely superior to the Niresist as regards resistance to creep at 850° C.

It may be noted that scaling and oxidation below the surface cause appreciable wastage, particularly in the case of Niresist, and it is probable that this affects the life under stress of the relatively small specimens used. For larger specimens the wastage factor would presumably be less pronounced.

At 850° C. a thin protective scale appears to be produced on Silal, but after 15 days, as shown in Fig. 50, the structure is not greatly affected, apart from a possible slight thickening of the graphite flakes.

The scale produced on Nicrosilal seems also to behave in a protective manner, and the wastage is not excessive after 40 days at 850° C. On the other hand, a certain amount of decarburisation occurs beneath the scale, whilst in the particular sample examined grey-coloured crystals were observed in the metal some distance below the surface. The position and appearance of these crystals are shown in Figs. 51 and 52. The austenite appears to remain unchanged during service at 850° C.

After the specimen of Niresist cast iron had been tested for growth at 850° C. for 42 days, it was found to have a very hard skin, of depth about 0·05 in. The skin or scale adhered quite firmly, and was not readily detached except by hammering.

The structure at the junction of the skin and body of the material is shown in Fig. 53. The skin consists of material which has been partly oxidised in a uniform manner, that is, the amount of free metal in the skin is the same throughout its thickness. A thin zone, apparently containing a high proportion of oxide, is found at the junction of the oxidised and unoxidised material, whilst the reddish colour observed within the zone suggests the presence of small quantities of metallic copper, possibly the result of differential oxidation. A small portion of the skin was detached from part of the specimen by hammering it on an anvil. Although the quantity thus obtained was insufficient for a complete analysis, it was found that the portion soluble in warm hydrochloric acid contained 21% of nickel and 9% of copper; and on dissolving in hot hydrochloric acid, hydrogen was evolved equivalent to about 24% of free metal calculated as nickel. This indicates that roughly one-quarter to one-third of the skin consists of free metal.

The structure of the body of the material is illustrated in Fig. 54. The main structural characteristics of the Niresist cast iron have not been altered by exposure at 850° C., but the large number of specks suggests that a small amount of some constituent, possibly graphite, has developed in the austenitic solid solution.

Conclusions.

The results of the investigation show that the ordinary and nickel-chromium cast irons retain useful strength at temperatures up to 538° C. (1000° F.) but that in the condition as-cast the rates of growth and creep would be greater than those generally considered permissible for steam plant operating at this degree of superheat. The creep and growth properties of both irons may, however, be considerably improved by heat treatment below the critical temperature for a suitable period, say 5 days at 650° C. The growth which occurs at superheated steam temperatures appears to be

largely due to the graphitisation of the pearlite cementite, and the function of the heat treatment is to bring about most of this decomposition before the material is finally machined and put into service.

The resistance to creep and growth of Silal cast iron at 538° C. is much greater than that for ordinary and nickel-chromium irons and is, in fact, of the same order as for these irons in the heat-treated condition referred to above. In view of the low combined carbon content of the Silal, this is not surprising, and the effect of heat treatment at about 650° C. has not been investigated, as little improvement seems likely to be obtained with this iron.

Examination of the austenitic cast iron Nicrosilal indicates that the austenite constituent is unstable at 538° C., at 450° C., and probably at even lower temperatures. The rate and manner of breakdown are influenced to some extent by slight changes in composition, and by heat treatment at a temperature above 1000° C., but the ultimate result is little affected. The austenite breakdown causes a comparatively rapid growth and creep, and it appears, therefore, that at such temperatures Nicrosilal is unsuitable for service where permanence of dimensions and retention of the austenitic condition are essential.

On the other hand, the austenite constituent of Niresist cast iron is stable at 538° C. and 450° C., and this iron possesses good growth and creep properties at these temperatures. Actually the growth and creep at low stresses appear to be less at 538° C. than at 450° C., and although the reason for this is not clear, it is possibly not unconnected with the more rapid graphitisation and the earlier attainment of a stable state at the higher temperature. In view of experience gained during the research it seems likely that the growth and creep properties of Niresist might be improved at superheated steam temperatures by giving a preliminary heat treatment, such as has been applied successfully to the ordinary and nickel-chromium irons. In this event the properties at 538° C. and 450° C. might assume the more usual relationship.

In regard to properties at 850° C., it has been shown that the growth of the Nicrosilal cast iron is less than that of the Niresist iron, and much less than that of the Silal iron. As far as resistance to creep at 850° C. is concerned, the results of the single tests at 1 ton per sq. in. indicate that the Nicrosilal, particularly that of the second batch, is superior to the Niresist. A hard layer of partly oxidised metal is formed on the surface of Niresist at 850° C., but it appears that this is less protective against further oxidation of the underlying metal than is the thinner scale formed on Nicrosilal and Silal.

Acknowledgments.

The investigation of the properties of cast irons forms part of the current research carried out at the National Physical Laboratory

on behalf of the Committee on the Behaviour of Materials at High Temperatures of the Department of Scientific and Industrial Research, to whom the authors are indebted for permission to publish the results. The thanks of the authors are due to Dr. H. J. Gough, M.B.E., F.R.S., Superintendent, Engineering Department, and to Dr. C. H. Desch, F.R.S., Superintendent, Metallurgy Department, National Physical Laboratory, for their interest and encouragement in the work, and to Dr. C. H. M. Jenkins, Metallurgy Department, National Physical Laboratory, for his valuable help and advice.

DISCUSSION.

Mr. J. G. PEARCE (Birmingham) said the paper was the most comprehensive contribution on the creep properties of cast iron which had yet appeared in any country, and it was one on which the authors were to be warmly congratulated. There was no attempt to determine the creep properties with reference to systematic changes in composition or structure. Of the five materials tested, the first was a straight cast iron of a type which was very widely used in the construction of engineering castings, and not, of course, designed particularly to resist heat. The second was an alloyed cast iron of the low-alloy type used for special castings. Those two served to provide a datum, and in the second iron regard must be paid to the fact that it had a higher silicon content than the first, making allowance for the alloy additions. The three remaining irons were comparatively new. Silal had been described before the Institute in 1931,[1] and its properties had since been confirmed in several other countries.[2] The tendency to growth and oxidation was reduced by using a high-silicon ferritic matrix with a low carbon content and finely divided graphite, and it was interesting to note that Gough and Pollard [3] had recently given to the Institution of Mechanical Engineers some very interesting figures relating to the fatigue properties of this material, which had an endurance ratio of virtually unity. Niresist was a now well-known austenitic iron containing nickel, copper, and chromium, well treated in the reference given by the authors. Nicrosilal was also rendered austenitic by nickel, silicon, and chromium, and had been described before the Institute in 1932.[4]

In the experiments given in the present paper, it was desired to use commercially-made materials, in spite of the fact that so far as the three heat-resisting irons were concerned the makers at that date had comparatively little experience. To-day he thought that the materials would be more uniform and the results better. The relative instability of certain compositions forming martensite from the austenite at medium temperatures was known, and it was recognised that the first batch of Nicrosilal tested might give some difficulties in that respect, but it was believed that the second batch would be quite stable; however, in the long-period tests which were used by the authors it did suffer to some extent at the temperatures used, but the demand which had to be met by special irons of this

[1] Norbury and Morgan, *Journal of the Iron and Steel Institute*, 1931, No. I., p. 413.

[2] Mitsche and von Keil, *Giesserei*, 1931, vol. 18, Mar. 6, p. 200; Le Thomas and Olinger, *La Fonte*, Jan., 1933; Thyssen, *Journal of the Iron and Steel Institute*, 1934, No. II., p. 153.

[3] *Proceedings of the Institution of Mechanical Engineers*, 1935, vol. 131.

[4] Norbury and Morgan, *Journal of the Iron and Steel Institute*, 1932, No. II., p. 301.

type arose in furnace and other plant operating at substantially higher temperatures than those originally used in the paper, which were governed by the requirements of modern steam plant. It was gratifying, therefore, that it was found possible to include some tests at 850° C., at which temperature, of course, the austenite was quite stable. At the lower temperatures growth mainly arose from graphitisation, and it might be recalled that Benedicks gave 2% as a possible volume increase due to this. At higher temperatures oxidation also proceeded, and the dimensional change arising therefrom could be very much more serious. At the lower temperatures it was clearly an advantage to heat-treat the material in such a way as to decompose the pearlitic cementite.

The authors remarked that Silal had a creep and growth resistance of the same order as the ordinary and low-alloy irons after heat treatment, which was tantamount to suggesting that it was equivalent to the growth of an iron after the capacity for growth had been removed, at any rate so far as temperatures at which oxidation did not occur were concerned. It must be borne in mind, however, that the heat treatment of castings was not always practicable, and that, in any case, where the pearlitic carbide was broken down the strength was reduced, as was well shown in the paper. Such treatment, while it was actually carried out in suitable cases, was not intended for general application.

Broadly speaking, the best type of heat-resisting iron to suit a given set of conditions was a matter of choice from a variety available, and the data given in the paper would be of enormous assistance in adding to what was already known; it was, incidentally, of a type for which frequent requests were received. Making due allowance for the factors mentioned, the results generally fell into line with expectations.

He would like to conclude by referring to the figures which had been given by an independent worker, Dr. Inglis, for various applications, but not primarily with regard to steam plant con-

TABLE A.

	Temperature at which Serious Deterioration occurs (Growth and Scaling). °C.	Temperature at which Appreciable Scaling occurs. °C.	Recommended Maximum for Practical Use. °C.
Ordinary cast iron . .	500	500	450
Pearlitic cast iron . .	650	500	550
1% chromium cast iron .	750	550	600
Silal (4–10% Si) . .	900	800	750
Nicrosilal and similar high-chromium and nickel-chromium cast irons .	No change up to 1000	900	950

ditions.[1] The " ordinary cast iron " was presumably an iron with a mixed structure of ferrite and pearlite, while the 1% chromium cast iron was a well-known type of heat-resisting iron (*see* Table A).

Mr. W. T. GRIFFITHS (London) said that the paper contained the report of a series of valuable observations of a type which had now come to be expected regularly from co-operation between the engineering and metallurgical departments of the National Physical Laboratory. He thought, therefore, that it was rather unfortunate that, even taking account of the time when the experiments were initiated, the authors should refer to their irons as " typical." In particular, he thought it was a pity that they had referred to what they called throughout the paper " nickel-chromium cast iron " as typical. As one who had had not a little to do with the development of alloy cast irons in Great Britain, he wondered of what it was typical. It was certainly not typical of what were called the alloy high-quality cast irons of to-day, or such as had been in existence for several years, and, with its silicon, phosphorus, nickel, and chromium contents, it was also not typical of any iron which would be suggested by anyone for service where even only occasionally temperatures much above normal were encountered.

The matter was one of perhaps general importance. Considerable sums of money contributed by the Government and by the industry were being spent to-day on research. It was very desirable, he considered, that the results of these researches should be made available as soon as possible, and particularly that they should be such that they could be applied relatively promptly. He wished, therefore, to appeal to all those committees and others who were responsible for initiating and controlling this research to take every possible precaution to ensure that the materials employed were typical, and that the results obtained on them could be given general application. This was important, not only from the point of view of economy, but also because new information of the type which the National Physical Laboratory was supplying was so urgently needed that the country and industry generally could not afford to spare the valuable time of the research workers.

The paper was of particular interest in connection with the effect of silicon on cast irons which might have to resist temperatures above normal. In the so-called pearlitic or α-iron cast irons two effects had to be considered. When the silicon content was on the low side, it was well, as had been shown by Carpenter and others, to keep the content as low as possible, owing to its effect on graphitisation and oxidation, resulting in growth. If it was correct, as had been suggested in the paper, that the silicon content of the nickel-chromium cast iron had been raised to counteract the influence of the chromium, that was certainly the wrong way to do it in iron for use at high temperatures.

[1] Inglis, *Transactions of the Society of Glass Technology*, 1933, vol. 17, p. 366.

On the other hand, as Pearce and his co-workers had shown so admirably, when the silicon content was raised to 4, 5, or 6% an entirely different effect came in, namely, protection against oxidation and penetration of oxidation, resulting in the low growth and useful properties of Silal.

In connection with austenitic iron or γ-iron cast irons the effect of silicon had to be watched in an entirely different connection, namely, in its influence on the stability of the austenite. Study of the stability of austenite in cast irons had been under way in the speaker's laboratory for some months. The results had not yet reached a stage when they could be reported, but they hoped to have the privilege of reporting them to the Institute at some date in the near future.

Already it seemed clear, however, that if the silicon content were increased to produce a cast iron of the Nicrosilal type it was necessary to make other modifications of the composition specially in order to counteract the effect of the silicon in making the austenite unstable at intermediate temperatures and giving rise to change of dimensions by the production of martensite or sorbite. It would be observed from the results in the paper that this breakdown of austenite was not noticeable in Niresist, presumably because the silicon content was of a different order. It must not be assumed from this, however, that high-silicon austenitic irons could not be used at the temperatures in question, since it seemed likely that by suitable adjustments—of the nickel content, for example—a degree of stability could be ensured.

One interesting feature had emerged in their experiments, which was actually in line with some previously published results regarding steels, and this was that the breakdown to martensite did not take place at the temperatures of heating, namely, 500–700° C. A change certainly did go on at these temperatures, but the transformation from austenite to martensite, which was, of course, accompanied by an expansion, apparently occurred on cooling at temperatures of the order of 150–200° C. This might be of importance in connection with the stability of dimension and lack of distortion in castings submitted to repeated heating and cooling.

One or two minor points in connection with the paper might be mentioned. The suggestion was made that some of these high-alloy cast irons had been developed for use at temperatures of the order of 850° C. This was certainly not the case with Niresist, which had, indeed, first of all been developed as a corrosion-resisting cast iron which could be made reasonably cheaply. It had actually proved of service in some high-temperature applications, but not for temperatures as high as some of those mentioned. Unless a very complete support for the cast iron could be provided, he thought that strength considerations would prevent the use of a cast iron of any type, the field being, indeed, one more for the variety of heat-resisting steels and other alloys now available.

The effect of preliminary ageing was extremely interesting. While he agreed with Mr. Pearce that the heat treatment of cast irons or the annealing of cast irons was not a thing one always wanted to do, yet if it were possible, as the authors suggested, by this preliminary ageing to give to the low-alloy content cast irons in question properties at high temperatures which were satisfactory from a creep point of view, then he thought that it might be worth while following up the suggestion.

Some of these irons had very useful properties at ordinary temperatures, and if use could be made of these, and particularly their toughness and freedom from brittleness, they might have a use at these medium temperatures if it were possible to get rid of growth. By using a suitable combination of nickel, chromium, and silicon, further diminution of growth could be accomplished, and he hoped it would be possible at some time for tests to be carried out on a suitably balanced iron of this type.

Dr. A. L. NORBURY (Birmingham) said that the authors' results agreed very well amongst themselves and were very convincing. Their tests were not, of course, carried out in an atmosphere of superheated steam, but he would like information as to the nature of the atmosphere and the extent to which air circulated round the specimens during test and caused growth due to internal oxidation.

He would like to make some observations on the compositions of the irons tested, as given in Table I. of the paper. The ordinary iron was a low-manganese cast iron, and its manganese content of 0·28% was insufficient to neutralise the 0·12% of sulphur present. In cast iron about 0·3% of manganese in excess of that required to form manganese sulphide was necessary to neutralise the sulphur. Some of the sulphur in the iron in question was therefore not neutralised, and would have a powerful effect in stabilising the combined carbon That would account for the high combined carbon content of 1·10% in Table I., and would also retard the decomposition of that combined carbon into graphite during the creep tests and during annealing. If the manganese content of the iron had been about 0·5% the combined carbon content would have been lower, and it would have decomposed more rapidly on heating. He was not suggesting that the iron was not a typical one, but merely calling attention to certain characteristics of its composition.

The nickel content of the Niresist was higher than the usual 14%. That difference was important from the point of view of the stability of the austenite, and also, of course, it was important economically.

With regard to the composition of the Nicrosilal tested, and the effect of composition on its breakdown on heating at 450° C. and 538° C., attention was drawn to this breakdown in the original paper on Nicrosilal [1] and it was stated that compositions " contain-

[1] Norbury and Morgan, *Journal of the Iron and Steel Institute*, 1932, No. II., p. 318.

ing less than about 5% of silicon and more than about 17% of nickel were stable and were not hardened even after several 15-hr. annealings round about the most dangerous temperature," about 500° C. The authors had, however, shown that irons of such composition did decompose to a certain extent on the more prolonged heatings which they gave them—for example, 40 days at 538° C.—as seen in Fig. 42. If the micrographs in Figs. 40 and 42 were compared, it would be seen that the iron depicted in Fig. 42 had broken down very much less than that shown in Fig. 40, and the suggestion was that a still further reduction in silicon content and increase in nickel content would produce a composition of Nicrosilal which would not break down under those conditions.

There were one or two points with regard to the microstructures which he would like to mention. For example, in Fig. 23 he would like to suggest that the graphite fringes were of oxidised metal, as the authors suggested in the section on nickel-chromium cast iron, and that the graphite fringes in Fig. 19 were due to some polishing effect such as burnishing or breaking round the graphite flakes. In Figs. 44 and 45 the micrographs of the Niresist gave the impression that it contained more combined carbon than graphite, and yet the combined carbon was given only as 0·74% in Table I. Was it possible that that figure was too low, due to chromium carbide contamination giving too high a graphitic carbon content on analysis? In Figs. 28 and 29 was not the new constituent described by the authors in the ferrite pearlite, or the ghosts left by pearlite which had since decomposed? The pearlite in the high-silicon irons was very coarse and acicular, as shown in Fig. A (Plate XXIXA.). In Fig. 54, he thought that the specks in the austenite were probably carbide deposited from solid solution by annealing. It had been found that this did occur in such compositions.

In conclusion, he would like to say that his observations had been on points of detail only, and he wished to express his appreciation of the accuracy and usefulness of the authors' results and of the impartial manner in which they had presented them.

Mr. F. W. Harbord, C.B.E. (Past-President, London), joined with previous speakers in congratulating the authors on presenting a very lucid paper on a very interesting and important subject. He would, however, like to ask one question. He understood Mr. Pearce to say that the "ordinary cast iron" used in the experiments was typical of what was used for general engineering castings; he hesitated to suggest that that was not the case, in view of Mr. Pearce's wide experience, but it did seem to him that this iron was not what would usually be considered an ordinary grey foundry iron. The analyses given in the paper indicated that one-third of the carbon was in the combined condition, the silicon content was 1·27%, the sulphur 0·12% and the manganese 0·28%, and he would expect an iron of that composition to give a mottled fracture,

and it would not be typical of the ordinary foundry iron used for engineering castings. He might be wrong, and he only asked for information. In any case, it would have added to the interest of the paper if the authors had included a typical grey foundry iron with a little over 2% of silicon, and with the greater part of the carbon in the non-combined condition. This would have been intermediate between the low-silicon " ordinary cast iron " and the so-called Silal, which was only a trade name for ordinary high-silicon iron.

CORRESPONDENCE.

Mr. C. H. DAVY (London) wrote that as a description of the behaviour of certain cast irons under the effect of elevated temperatures, the paper appeared to be excellent, but it was unfortunate that the authors should have related the work to high-steam-temperature service, as, judging from the paper, the tests reported therein appeared to have been carried out under conditions in which steam had actually been absent.

It had been well known for a number of years past that superheated steam caused deterioration of cast irons in a manner which was not met with under high-temperature conditions in air, and, in consequence, before the results set out in the paper could be applied to the design of pressure parts subjected to the action of superheated steam, they would require to be modified, perhaps to a considerable degree.

The paper appeared to give no evidence upon which any one of the cast irons tested could be classed as suitable for steam service, and the authors' assumption that dimensional changes at high temperature were primarily responsible for the limitations set upon cast iron in the design of steam generators was hardly in accordance with the facts of the case.

Limitations had been set on the application of cast iron in steam boiler design almost thirty years ago, when superheated steam temperatures of 300° C. were exceptional, and it would be appreciated that high temperature effects could not have been the major factor in the placing of restrictions on the use of cast iron. The real reason for these restrictions was the action of steam and hot water on cast iron, in that breakdown occurred under such conditions at a more rapid rate than was the case where cast iron was required to withstand the action of air or flue gases only. The fact that steam as generated in boilers contained carbon dioxide and free oxygen might have an important bearing on the behaviour of cast iron in contact with these gases, and practical experience had indicated up to the present that cast irons were unsuitable for high temperature steam service.

Another condition, which was of almost equal importance, and which had not been treated in the paper, was the effect of repeated

FIG. A.—Coarse Acicular Pearlite in 6·0% Silicon Cast Iron. (Total Carbon 2·5, Si 6·0, Mn 0·5, Sb 0·5% approx.) × 1000.
(*See* Norbury's discussion.)

[*Tapsell, Becker, and Conway, discussion.*
To face p. 356 P.

FIG. B.—Malleable Cast Iron Nozzle after 2 years at 371–427° C. in superheated steam.
(*See* Parker's correspondence.)

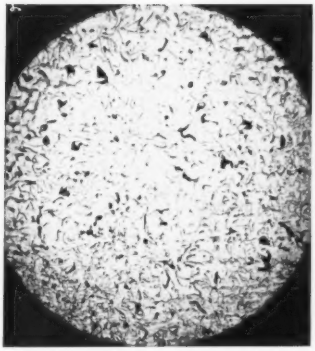


FIG. C.—As Cast. × 25.

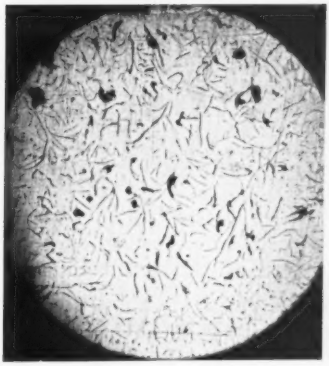


FIG. D.—After 359 hr. at 500° C. × 25.

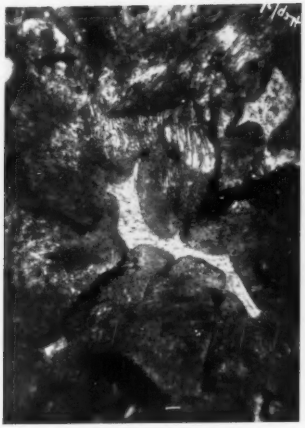


FIG. E.—As Cast. × 250.

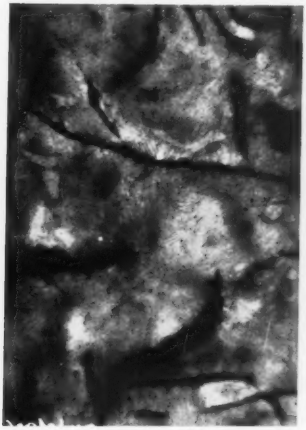


FIG. F.—After 359 hr. at 500° C. × 250.

(Micrographs reduced to two-thirds linear in reproduction.)

(*See* Parker's correspondence.)

[*Tapsell, Becker, and Conway, correspondence.*

heating and cooling. It was believed that certain of the cast iron alloys would have yielded different results for growth and creep had repeated heating and cooling been taken into account.

Mr. W. B. PARKER (Rugby) wrote that the paper was of considerable general interest. The part dealing with cast iron described as "ordinary" cast iron was a very useful confirmation of work performed by industrial laboratories connected with steam engineering works. There was always room for work of this kind, performed by a group of entirely disinterested investigators, and such work should evoke thorough discussion.

For a long time now it had been regarded by engineers as unsafe to employ ordinary (unalloyed) cast iron at any temperature above 232° C. (450° F.); the authors' work appeared to justify that opinion. This engineering opinion had been arrived at by a combination of laboratory and foundry researches, and especially the practical experience in the design and *working* of turbines; it was of slow growth and must still be considered as thoroughly reliable.

The question of the employment of cast iron in steam turbine engineering was not merely one of the temperature used and the grades of cast iron available, but also of the many design conditions and the expected duration of service. If the life of a turbine was taken as about 15 years it was clear that the time factor was so greatly extended that physical changes might become excessive, although this was not revealed by researches which extended for only 1500 hr.

At an early date the steadily increasing steam temperatures and pressures had brought this question to notice in connection with valve casings. Some time later it had arisen in respect of nozzle castings and finally nozzle diaphragms; the sizes of the latter had increased greatly with the increased capacities of the machines. At the present time, cast iron was relegated to the lower temperature end of the machines. For this purpose a stress-relieving heat treatment at a comparatively low temperature sufficed to stabilise the metal, and did not damage it.

The writer wished to comment further upon a few points that arose from the authors' results and opinions.

(A) *Pre-Heat Treatment of Ordinary Cast-Iron Castings.*—Annealing the cast iron castings before use had been practised for many years, the original idea being to relieve casting stresses. The temperatures employed for this had varied as years sped, because they had to keep in tread, so to speak, with the march of increasing steam temperatures; but a time arrived when cast iron was no longer satisfactory for the high-temperature requirements, owing to the serious loss of strength occasioned in cast iron by the higher temperature deemed necessary for annealing, and required by actual designs.

The authors' work showed a 33% falling off due to annealing for

5 days at 650° C., but the writer had found a 40% decrease of strength at 400° C. in less time; this was in the case of actual castings, not small test specimens which cool rapidly.

In the case of large nozzle plates, this type of investigation had led to the opinion that a probable solution of the difficulty would be to employ malleablised cast-iron castings, since these had received a prolonged high-temperature annealing in the process of manufacture. The idea had been actually tried out between 1922 and 1925, blackheart malleable castings being employed, but they were no better in actual service than the grey cast iron.

The blackheart malleable castings had a ferrite plus graphite structure, with some phosphorus eutectic—in spite of the fact that the phosphorus was kept down to about 0·10–0·15%. This point was of interest in view of the similarity of microstructures shown in Fig. 48 to that usually found in the malleable cast-iron nozzle plates *after use*.

There were various types of trouble when employing malleable cast iron, and to help the authors to realise the difficulty of applying, in engineering practice, theories derived from laboratory investigations, one of these malleable cast-iron nozzle castings after 2 years' use at 371° to 427° C. was depicted in Fig. B (Plate XXIXB.).

No doubt one of the difficulties arose from the mass and the cross-sectional dimensions of such castings; also, there was the fact that in those days the actual nozzles were made by casting-in either mild-steel or alloy-steel rolled sheet metal, formed to the required shape.

Experiences such as the above, which revealed the behaviour of materials under actual working conditions, were surely superior to laboratory tests as real criteria of the engineering value of materials, and consequently the writer must challenge the authors' remark that "the comparative growth/time characteristics of ordinary . . . cast irons in the steam temperature range 700–1000° F. (371–538° C.) have not been demonstrated." Both laboratory work, small-scale and large-scale investigations *had* been performed at temperatures included in this range, but naturally the firms who paid for this pioneering work did not usually immediately publish their results in technical literature for the free use of their more backward competitors. The result of this actual experience plus laboratory work was that cast iron was not used in steam turbines for parts working at 450° F. to 1000° F. The only cure for these high-temperature troubles was the employment of steel; the alloy cast irons offered no advantage over mild steel and gave no real guarantee of safety during the long life of service demanded.

It was rather a pity that the authors did not conduct more and longer creep tests upon the un-heat-treated and heat-treated cast iron at the lower temperatures—say 400° C., 375° C., and 350° C. —which would have afforded data of immediate practical interest.

(B) *Short-Time High-Temperature Tensile Tests on Ordinary Cast-Iron Castings.*—For rapidly establishing safe temperatures for

the employment of cast iron this type of test had been very extensively employed for about 20 years. The character of this test, however, had to be of a more refined type than the authors appeared to have employed.

The writer had selected at random a series of tests made in 1922 upon what was then considered a fairly good ordinary grey iron. Of course, the metallurgy of cast iron had progressed somewhat since then, and the authors' samples should reflect this progress in the comparison.

The samples here reported upon were *cast-on* samples, *i.e.*, each formed an actual part of a steam casing; this point must be carefully noted. The tensile sample bars as cast were $1\frac{5}{8}$ in. in dia. by 20 in. long. The transverse sample bars as cast were $1\frac{1}{4}$ in. $\times$ $1\frac{1}{4}$ in. $\times$ 24 in. The average chemical analysis (derived from mixing drillings taken from all the bars) was as follows :

	%		%
Total carbon . . .	3·0	Phosphorus . . .	1·1
Graphitic carbon . . .	2·5	Manganese . . .	0·6
Combined carbon . . .	0·5	Sulphur	0·08
Silicon	2·0		

The short-time high-temperature tests obtained were given in Table B.

TABLE B.

Temperature. °C.	Transverse Test.		Tensile Test.			
	Modulus of Rupture. Tons per sq. in.	Modulus of Elasticity. Tons per sq. in.	(1) Proportionality Limit. Tons per sq. in.	(2) Maximum Stress. Tons per sq. in.	Ratio $\frac{(1)}{(2)}$ %	Modulus of Elasticity. Tons per sq. in.
20	20·9	5,860	5·5	12·1	45·6	5,170
100	21·9	6,130	4·5	11·5	39·1	5,653
200	21·0	5,880	4·5	11·9	37·7	5,675
300	21·6	5,770	4·6	11·2	40·9	5,600
400	21·1	5,410	3·5	10·7	32·7	4,710

In the section on creep and growth tests the authors mentioned the variability of the high-temperature properties of ordinary cast iron. This was a well-known fact, and it was not to be wondered at, nor ignored; it was due to the fact that with cast iron one was not dealing with a refined product like steel, but (usually) merely a re-melt of a mixture of carefully selected pig irons and various kinds of scrap, which produced a much more heterogeneous and cruder product than steel.

For some time—say thirty-five years at least—a great deal of careful control of the mixing, melting, and casting of grey cast iron had been exercised in the foundries of turbine-makers, but it had

not resulted anywhere in the absolute control of the physical and mechanical properties of grey cast iron. Further, what practical good would it be to obtain strict uniformity in separately cast sample bars when what the engineer wanted was uniformity in the *castings*? If the authors had used samples cast-on to castings instead of separately cast bars, they would have found the same difficulty respecting variability; in fact, this feature was one which reduced the suitability of cast iron for the exacting work of really high temperature constructions.

Nevertheless, by very great care in the control of the mixtures &c., a certain degree of uniformity of physical properties had been attained and maintained. A comparison of the results set forth in Table B with those given in Table C would illustrate the extent of the variability met in actual foundry practice. The short-time properties only were given, because long-time creep tests could not be used for control purposes.

The mixture and size of the samples were kept constant, and also all samples were cast-on to the castings.

TABLE C.

Temperature. ° C.	Transverse Test.		Tensile Test.			
	Modulus of Rupture. Tons per sq. in.	Modulus of Elasticity. Tons per sq. in.	(1) Proportionality Limit. Tons per sq. in.	(2) Maximum Strength. Tons per sq. in.	Ratio $\frac{(1)}{(2)}$ %.	Modulus of Elasticity. Tons per sq. in.
20	19·2	5,913	5·7	12·5	45·4	5,420
100	21·4	6,116	5·0	12·2	41·0	6,120
200	20·3	5,796	5·1	12·9	49·6	6,160
300	21·2	5,785	5·0	12·3	40·6	6,600
400	23·6	5,495	3·6	11·12	32·2	5,280

In each series the values stated represented averages for ten samples for *each* temperature and *each* type of test.

There was one very definite fact about these two sets of results, namely, that the strength of the metal fell off at 400° C. (752° F.), and this was a clear hint to any metallurgist that it was *not* safe for higher temperatures.

Under the heading " Ordinary Cast Iron " the authors discussed the changes in microstructure produced by high temperatures and stated that " the structural changes . . . depend upon the time of exposure rather than upon the magnitude of the stress "; this was correct—stresses, *per se*, of the magnitude reported could not produce structural changes, but could produce structural damage, and most certainly would do so if the stress exceeded the proportionality limit of the metal at the particular temperature employed. The authors did not appear to have tried to follow the chemical changes

produced by heating, some of which could account for the structural changes noted, but of which others were more hidden. The task was troublesome because of sampling difficulties, but in research work it was worth trying occasionally.

Some years ago the writer and his staff made an attempt to trace structural changes by the chemical changes occurring during an investigation upon actual nozzle diaphragm castings, 40 in. in dia., taken from current stock. The casting was carefully sampled and analysed prior to heat treatment, and the mean ultimate analysis was found to be as follows (note that the combined carbon was just half that in the authors' sample):

	%		%
Total carbon	3·165	Silicon	1·550
Graphitic carbon	2·638	Phosphorus	0·343
Combined carbon (difference)	0·527	Manganese	0·487
Combined carbon (by colour)	0·533	Sulphur	0·090

Iron (by difference)	94·365%
Phosphorus in solid solution	0·150%
Phosphorus in eutectic	0·193%

The casting was then placed in a coal-gas-fired annealing furnace in such a way that the heat and products of combustion could circulate both over and under it. In this furnace it was submitted to 500° C. for 5 days of 24 hr. continuous heating per week (120 hr. per week), which treatment was continued for 4 weeks (480 hr. total).

The reason for the intermittent heating was to enable deflections and certain dimensional changes to be followed. In one case the casting was unstressed, and in another it was loaded with the designed working stress. The castings remained in the furnace during the coolings to air temperature.

The unstressed casting was re-sampled after each of the first three weeks' treatment, care being taken to avoid any decarburised metal and to obtain as good an average sample as that employed for the original analysis.

From the ultimate analysis (per cent. by weight) so obtained the rational analysis (by weight) was calculated, using a certain conventional scheme, and also the structural composition by volume, and these were correlated with the microstructures of corresponding specimens.

It would be observed from Table D that the combined carbon was determined by the difference between the combustion results for total carbon and graphitic carbon, *also* by the colorimetric method (using a proper standard for comparison), since it was believed that for such material the colour test gave a very good measure of the actual carbide carbon, and it most probably did not include or record the carbon which was in the form of solid solution

TABLE D.

Element.	Condition of Material.			
	As Cast.	Heated at 500° C. for—		
		121 hr.	241 hr.	359 hr.
Ultimate Analysis by Weight.				
Total carbon, %	3·165	3·300	3·244	3·267
Graphitic carbon, %	2·638	2·760	2·772	2·765
Combined carbon (by difference), %	0·527	0·540	0·472	0·502
Combined carbon (by colour), %	0·533	0·506	0·450	0·457
Silicon, %	1·550	1·540	1·426	1·548
Total phosphorus, %	0·343	0·200	0·236	0·231
Manganese, %	0·487	0·525	0·506	0·523
Sulphur, %	0·090	0·016	0·014	0·014
Iron (by difference), %	94·365	94·419	94·574	94·417
Phosphorus in solid solution, %	0·150	0·158	0·167	0·171
Phosphorus in phosphide, %	0·193	0·062	0·060	0·058
Rational Analysis by Weight.				
Graphitic carbon, %	2·638	2·760	2·772	2·765
Cementite, Fe_3C (total), %	7·56	6·608	6·93	7·28
Manganese carbide, Mn_3C, %	0·355	0·527	0·516	0·519
Phosphide of iron, Fe_3P, %	1·239	0·398	0·385	0·372
Phosphorus in solid solution, %	0·150	0·158	0·167	0·171
Manganese sulphide, %	0·245	0·043	0·038	0·038
Silico-ferrite (Fe + Si), %	33·812	40·580	37·772	35·266
Free eutectoid iron, %	52·019	47·073	49·094	51·303
Free eutectic iron, %	1·982	1·853	2·326	2·286
Analysis by Volume.				
Graphitic carbon, %	8·440	8·831	8·867	8·845
Cementite, Fe_3C, %	7·370	6·443	6·756	7·097
Carbide of manganese, Mn_3C, %	0·371	0·551	0·540	0·543
Phosphide of iron, Fe_3P, %	1·155	0·371	0·359	0·346
Manganese sulphide, MnS, %	0·442	0·077	0·068	0·068
Free eutectoid iron, %	47·749	43·210	45·065	47·093
Free eutectic iron, %	1·818	1·700	2·134	2·098
Silico-ferrite plus phosphorus in solid solution, %	32·655	38·817	36·211	33·910

in the silico-ferrite, or even that in the phosphide eutectic. This point could not be further discussed now, but any one interested should review the paper by J. E. Stead presented to the British Association at Sheffield in 1910.

It would be noted that in the original metal the combined carbon obtained by difference was lower than that found by colour test, but in all three annealed samples the case was reversed.

In addition to the determination of the total phosphorus, the percentages in solid solution and as free phosphide (*i.e.*, eutectic) were determined by Stead's method.

It was originally intended to determine the sulphur by the evolution method, in addition to the gravimetric results actually reported, but in view of the big drop caused by the annealing (which was not explicable), it was not thought worth while doing this. People interested in this type of testing would find some results for pig irons given in Table VI. of the writer's paper entitled "Specifications for Foundry Pig Irons (Part II.)." [1]

The phosphorus results showed that a peculiar change in its chemical condition had occurred, and that there had been some loss of total phosphorus. This was particularly shown up in the rational and volume analyses; but to what extent and in what direction this had affected the physical properties of the metal it was difficult to say, because the mechanical tests were unfortunately confined to the tensile and transverse tests. Repeated impact tests might have cleared up this point.

Evidently the total percentage of combined carbon fell as the annealing proceeded, and apparently this decrease was concerned with the carbide carbon (cementite, Fe_3C). The amount in solid solution in the silico-ferrite appeared to remain constant at an average of 0·032%. But it was doubtful whether a total change of combined carbon of the order of 0·083% could account for the falling off in tensile strength, which was given in Table E (using cast-on samples).

TABLE E.

Material.	Tensile Strength. Tons per sq. in.	Transverse Test. Bars 1 in. × 1 in.; Span, 12 in.
Original (tests at room temperature):		
a	13·98	2552 lb.
b	12·45	3051 lb.
c	12·25	(actual breaking load)
	Average 12·89	2801 lb. average
After 121 hr. at 500° C. .	11·25	No transverse specimens available.
After 241 hr. at 500° C. .	11·47	
After 359 hr. at 500° C. .	11·10	
	Loss 1·79	

The original and final microstructures were shown at low and medium magnification in Figs. C, D, E, and F (Plate XXIXc.). The metal was a good pearlitic type of cast iron. The main features shown were a considerable increase in the size (particularly length) of the graphitic carbon flakes—compare Figs. C and D—also a decrease in grain size of the pearlite, with development of what appeared to be nebulous ferrite areas, as though the pearlite ground-mass was

[1] *Proceedings of the British Foundrymen's Association*, 1912–1913, p. 268.

becoming less extensive. It was also noticed that after annealing the phosphide eutectic did not so readily show its common structure, *i.e.*, it tended to be featureless.

It was concluded that the increase in length of graphitic flakes was most destructive to the mechanical properties, and since this occurred at 500° C. in only 359 to 480 hr., which was a mere fraction of the duration of the service demanded of such castings, it was too risky to employ cast iron at that temperature.

As already stated, this large-scale test was performed upon two castings, one in an unstressed condition and the other stressed with a load equal to that which would occur in the actual turbine if the latter had been constructed to use cast iron.

It could not, therefore, be inferred that when fixing temperature limits for cast iron designers had been, and still were, ignorant of the strain/time characteristics of cast iron in the range 700–1000° F.

In conclusion, it must be remembered that serious risk to life and property might result from failures of parts in high-speed machinery, and that the risk to life was greatly increased by these high steam temperatures and pressures, consequently great caution had to be exercised in all advances made in design and manufacture.

Mr. T. E. Rooney (National Physical Laboratory) wrote that he had been interested in the discussion on this paper at the meeting. Some observations were made on the composition of the irons used. The writer regarded the ordinary cast iron as a close strong iron suitable for engineering purposes. He had had experience with an iron of similar composition with the exception that the manganese content was somewhat higher. The iron was used for castings for locomotive cylinders. He did not regard the value for combined carbon as unusual, having regard to the silicon content. He did not altogether agree with Dr. Norbury's explanation of the reason for the high combined carbon content. It was possible, with a manganese content of 0·5%, silicon 1·20%, and sulphur 0·12%, to obtain a white fracture. He thought, therefore, that the combined carbon content was much more dependent on the silicon content and the melting and casting conditions than on the relationship between the manganese and sulphur.

With regard to the effect of chromium carbide on the estimation of graphitic carbon, this effect had not been overlooked in carrying out the analysis, and, from the amount and appearance of the residue after combustion of the graphite, it was not considered possible that sufficient chromium carbide remained undecomposed to affect the result appreciably. The effect of chromium carbide should also be noticeable in the case of the nickel-chromium and Nicrosilal irons. It would be unwise to state that there was no effect, but any effect was probably not appreciably outside the limits of accuracy of the method. The writer thought that it was rather risky to deduce the graphite content from one or two small microsections.

The nickel-chromium iron had been criticised, and the writer had carried out some scaling tests in a " flue-gas mixture " on this sample. He had been rather surprised that such a low content of nickel and chromium had made a decided improvement in the scaling properties as compared with the ordinary iron.

The writer had seen the analytical results communicated by Mr. Parker, showing the difference between the values for the combined carbon obtained by a combustion and a colorimetric method. In this connection it would be interesting to know the limits of accuracy of the two methods. It might be an advantage to present the values as follows :

		As-Cast.	Heated at 500° C. for—		
			121 hr.	241 hr.	359 hr.
Combined carbon by difference.	%	0·53	0·54	0·47	0·50
Combined carbon by colour.	%	0·53	0·51	0·45	0·46

When presented in this manner the values given by the two methods did not differ by much more than would be represented by the limits of accuracy of the methods employed.

AUTHORS' REPLY.

The AUTHORS, in reply, thanked Mr. Pearce for his remarks and references concerning the irons used in the research. They felt that Mr. Pearce had answered some of the criticism raised by Mr. Griffiths, but they would like to assure the latter that the question as to the most suitable irons to test had been very carefully considered in the first place by the Committee on the Behaviour of Materials at High Temperatures and by The British Cast Iron Research Association. In particular, Mr. Griffiths seemed to object to the choice of the iron which had been referred to as the " nickel-chromium cast iron." The special alloy additions were, no doubt, lower than Mr. Griffiths would recommend in a modern alloy high-quality cast iron, but it should be remembered that this particular iron was not chosen as representative of the highest-quality α-iron or pearlitic heat-resisting irons, but as a much less costly ordinary iron, to which small alloy additions were made in order to control the structure and render it fairly uniform throughout the casting. Cast irons of this type as well as of the type referred to as " ordinary cast iron " had been in use for cylinders, liners, and the like for a number of years, and, as Mr. Pearce had pointed out, it was desirable to obtain data regarding their behaviour in creep and growth in order to provide a basis for comparison with the test results on irons which had been and were being developed expressly to resist growth, creep, scaling, or corrosion at elevated temperatures.

The authors agreed with Mr. Griffiths in regard to the effect of silicon in pearlitic or α-iron cast irons for use at high temperatures, say, above 700° C. The fact that the nickel-chromium iron

contained over 2% of silicon showed that this iron was not specially designed for high-temperature service; but this was no reason why the iron should not be used in the lower temperature range with which the investigation had been primarily concerned. They were interested in his remarks concerning the effect of silicon in reducing the stability of the austenite in the austenitic cast irons. The austenite of Niresist was certainly more stable than that of Nicrosilal at temperatures around 500° C., but might this not be attributed partly to the copper content of the Niresist? The austenite was stable in Niresist at 500° C., but, as was shown in the paper, the carbides were not stable.

Dr. Norbury had called attention to the fact that the creep and growth tests were not carried out in super-heated steam. Air circulated round the specimens during test, but the authors had no evidence that oxidation had much influence on the creep and growth of the specimens at temperatures up to 538° C. (1000° F.), although for very much longer periods than those of the tests it was possible that oxidation effects might become appreciable. At higher temperatures, as was well known, oxidation became an important factor in causing growth.

It was realised that the manganese content of the ordinary iron was rather low in relation to the sulphur, but as the iron had been supplied through The British Cast Iron Research Association, the authors had concluded in the first place that this rather undesirable feature did not warrant rejection of the material.

Dr. Norbury confirmed that the graphite fringes in the nickel-chromium iron which had been heated during test were of oxidised metal, but the authors could not agree that the thinner lines surrounding the graphite in the condition as received were due to some polishing effect. On the contrary, burnishing tended to obliterate the lines, and the authors believed that they represented thin cracks possibly caused by contraction during solidification. It was likely that such cracks, if present in the original casting, would gradually fill with oxide and would, therefore, become more marked as the period of exposure increased.

The question of the combined carbon content of the Niresist was dealt with in Mr. Rooney's contribution, and the authors felt they had nothing more to add. They thanked Dr. Norbury for his suggestion concerning the constituent which they had been unable to identify in Silal, and in view of his remarks and photomicrograph they were strongly inclined to the view that the constituent was pearlite or the trace of pre-existing pearlite.

The authors desired to refer Mr. Harbord to their previous remarks concerning the advice they received before selecting the irons for test.

With regard to the remarks by Mr. Davy, the authors' investigations were concerned with the effects of stress at super-heated steam temperatures, but not with the effects of steam;

their conclusions that dimensional changes due to growth limited the use of cast iron at these temperatures were drawn in relation to the conditions under which the irons were tested, *viz.*, in air. Provided that the critical point of the cast iron at about 700° C. was not exceeded, it was doubtful if repeated heating and cooling would have any appreciable influence on the creep and growth.

The authors thanked Mr. Parker for the useful data contained in his contribution to the discussion. Some of the points raised were dealt with by Mr. Rooney, of the National Physical Laboratory, who carried out the chemical analyses of the irons for the authors. Mr. Parker challenged the authors' statement that the comparative growth/time characteristics of the irons had not previously been demonstrated, and then proceeded to say that work had been performed, but no results had been published. To the public, therefore, the facts had not previously been demonstrated. Tests at 350–400° C. on un-heat-treated and heat-treated cast iron suggested by Mr. Parker would probably be of interest. The authors might have followed up several points of interest arising in the investigation, but the range of their work was purposely limited. The chemical and microscopical tests were somewhat subsidiary to the mechanical tests, and, as already stated, the authors concluded their investigations when a stage was reached at which the trend of the behaviour of the cast irons at certain temperatures in air had been demonstrated and had opened up possibilities of extended research by industry.

THE EMBRITTLEMENT OF HIGH-TENSILE ALLOY STEELS AT ELEVATED TEMPERATURES.*

By W. E. GOODRICH, M.Met., A.M.I.Mech.E. (Sheffield).

Synopsis.

The paper records the results of an investigation conducted on twenty-seven high-tensile alloy steels, to ascertain some of the factors influencing the embrittlement of these steels when subjected to a temperature of 450° C. Nickel-chromium, chromium-molybdenum, nickel-molybdenum, chromium-tungsten-molybdenum, and several types of nickel-chromium-molybdenum steels were included in a number of tests covering a period of 2400 hr. Evidence was obtained on the effects of the presence of a maintained tensile stress during the soaking period; of fluctuations of temperature; and of initial heat treatment and variations in chemical composition. Strain-age-embrittlement tests were also carried out at 200° C. and 450° C. on samples subjected to initial permanent tensile strains varying within the limits 0 to 5·0%. Hardness and microstructural changes, resulting from the embrittlement treatments, were also examined.

As a result of the evidence obtained, it was considered that a mildly alloyed chromium-molybdenum steel was the most resistant to embrittlement; the use of the highest tempering temperature, consistent with the production of the required tensile strength, was an advantage; the presence of a maintained tensile stress of 11·0 tons per sq. in., or exposure to fluctuations of temperature below 450° C., had no influence on the ultimate embrittlement produced by soaking at that temperature; the amount of embrittlement was not sensibly influenced by the presence of initial permanent strain up to 5·0%; and that no changes in Brinell hardness or microstructure could be found to account for any embrittlement produced.

A difficulty experienced in the successful operation of plant working at elevated temperatures has been the premature failure of stressed components such as flange studs and bolts on superheater and boiler pipe lines. After removal, it has been found in many cases that the impact value of that portion of the component subjected to the elevated temperature, and also possibly subjected to fluctuating stresses brought about by temperature or pressure variations, was considerably lower than the original impact value of the material. Little evidence on high-tensile alloy steels being available, and such evidence not being sufficiently conclusive in regard to the effect of different percentages of alloying elements, it was considered desirable to carry out an investigation on several types of steel to ascertain those which were most resistant to embrittlement, and, if possible, determine some of the controlling factors. Temper-brittle nickel-chromium steels were included, and also

* Received February 11, 1936.

various types of nickel-chromium-molybdenum, chromium-molybdenum, nickel-molybdenum, and chromium-tungsten-molybdenum steels. Where possible, at least two different casts of each type of steel were included to ascertain whether the results obtained were typical of that particular chemical composition, or only applicable to one particular cast of that material. All the materials were heat-treated, in the form of rolled bars of $1\frac{1}{8}$ to 2 in. in dia., to approximately 65·0 tons per sq. in. tensile maximum stress. Izod impact tests were carried out on the standard 10 mm. square section in a 120-ft. lb. machine, and the tensile tests were conducted on samples of 2·0 in. gauge length and 0·564 in. in dia.

TABLE I.—*Analyses of Steels Investigated.*

Mark.	C. %	Si. %	Mn. %	S. %	P. %	Ni. %	Cr. %	Mo. %	W. %
A	0·31	0·226	0·57	0·016	0·018	0·61	0·97	1·16	...
B	0·275	0·188	0·49	0·012	0·017	0·86	0·88	1·12	...
*B*1	0·32	0·207	0·48	0·022	0·021	0·96	0·97	0·81	...
C	0·325	0·127	0·44	0·033	0·013	0·68	0·83	1·12	...
*C*1	0·295	0·249	0·52	0·021	0·019	0·71	0·90	1·10	...
D	0·21	0·215	0·45	0·029	0·030	0·04	0·64	0·40	...
E	0·23	0·212	0·56	0·025	0·031	0·08	0·62	0·51	...
*E*1	0·24	0·085	0·32	0·029	0·026	Nil.	0·62	0·43	...
F	0·28	0·207	0·58	0·032	0·030	Nil.	0·83	0·50	...
G	0·26	0·226	0·42	0·016	0·016	3·35	0·63	0·28	...
H	0·285	0·164	0·46	0·026	0·030	3·32	0·77	0·24	...
J	0·295	0·146	0·63	0·032	0·032	2·58	0·62	0·68	...
KI	0·31	0·169	0·56	0·027	0·031	2·43	0·58	0·54	...
K	0·31	0·122	0·38	0·019	0·032	2·49	0·50	0·63	...
L	0·44	0·164	0·56	0·027	0·028	2·56	0·62	0·63	...
M	0·41	0·165	0·56	0·033	0·031	2·36	0·62	0·60	...
NC	0·26	0·146	0·41	0·023	0·029	3·43	0·60	Nil.	...
NC(Ex.)	0·315	0·273	0·45	0·034	0·036	3·52	0·59	Nil.	...
N	0·37	0·33	0·49	0·040	0·030	Nil.	2·59	0·80	1·47
O	0·345	0·24	0·33	0·036	0·020	Nil.	1·97	0·68	1·42
P	0·41	0·165	0·53	0·038	0·029	Nil.	2·30	0·78	1·31
R	0·31	0·249	0·50	0·030	0·031	2·76	1·05	0·98	...
S	0·265	0·164	0·44	0·047	0·032	4·19	1·02	0·93	...
T	0·22	0·212	0·39	0·037	0·034	5·31	0·55	1·54	...
U	0·215	0·230	0·35	0·036	0·032	5·27	0·42	1·09	...
V	0·215	0·193	0·34	0·033	0·033	5·27	0·56	1·65	...
W	0·38	0·226	0·50	0·015	0·023	4·58	0·06	0·52	...

The analyses of the various steels are tabulated in Table I., whilst data on the heat treatments, initial Izod impact, and tensile values are recorded in Table II.

GENERAL EXPERIMENTAL PROCEDURE.

The heat-treated samples, in bar form, were subjected to a temperature of 450° C. in an electric muffle furnace, the temperature being automatically controlled to within $\pm$ 3° C. A sufficient

TABLE II.—*Heat Treatment and Mechanical Properties of Steels for Series I. and II.*

Mark.	Heat Treatment.	Yield Point. Tons per sq. in.	Maximum Strength. Tons per sq. in.	Elongation. %.	Reduction of Area. %.	Izod Value. Ft. lb.
A	O.H. 850° C. T. 650° C.	58·8	64·2	22·0	64·7	68
B	O.H. 850° C. T. 625° C.	62·1	67·3	22·0	66·4	78
*B*1	O.H. 850° C. T. 680° C.	53·9	59·5	23·0	64·0	72
C	O.H. 850° C. T. 695° C.	57·2	61·0	22·0	61·6	67
*C*1	O.H. 850° C. T. 635° C.	61·2	66·7	22·5	64·3	72
D	W.H. 850° C. T. 625° C.	47·8	54·7	21·0	66·0	72
*E*1	W.H. 850° C. T. 510° C.	58·7	66·5	16·0	56·0	50
F	W.H. 850° C. T. 610° C.	58·5	65·2	21·0	63·0	58
G	O.H. 850° C. T. 610° C.	60·1	65·1	23·0	64·7	67
H	O.H. 830° C. T. 650° C.	45·6	54·6	24·0	63·3	65
J	O.H. 830° C. T. 680° C.	43·8	56·0	24·0	64·7	78
K	O.H. 850° C. T. 625° C.	58·8	66·5	22·0	62·6	54
L	O.H. 830° C. T. 695° C.	47·2	66·6	20·0	44·8	64
M	O.H. 850° C. T. 635° C.	58·8	67·9	21·0	59·6	52
NC	O.H. 830° C. T. 600° C.	...	...	...	...	69
NC(Ex.)	O.H. 850° C. T. 500° C.	61·5	68·6	18·5	53·4	16
N	O.H. 875° C. T. 650° C.	59·9	67·4	18·0	54·5	40
O	O.H. 875° C. T. 650° C.	53·8	63·3	20·5	59·0	49
P	O.H. 870° C. T. 715° C.	58·9	59·3	22·0	59·6	56
R	O.H. 850° C. T. 685° C.	49·8	60·4	23·5	62·1	74
S	Supplied heat-treated.	55·0	63·6	21·0	61·6	56
T	O.H. 850° C. T. 650° C.	51·4	68·0	20·5	53·4	42
U	O.H. 850° C. T. 650° C.	54·8	65·4	20·5	54·8	38
V	O.H. 850° C. T. 650° C.	53·6	65·8	21·0	54·8	38
W	O.H. 850° C. T. 650° C.	50·4	62·4	20·5	52·4	63

number of bars of each steel to give two Izod impact test-pieces, each having two notches, was withdrawn from the furnace after the requisite time interval, the bars being allowed to cool in air. Izod test-pieces were then prepared from the centre of each bar, and tested at normal temperature, in order to furnish the data recorded in graphical or tabular form in the succeeding portions of this contribution. The Brinell hardness values of the materials before soaking at 450° C., and after long soaking at that temperature, were also determined.

SERIES I., SECTION 1.—TESTS ON UNSTRESSED STEELS.

Twelve steels of different compositions were selected for the first tests, and representative test lengths were subjected to a constant temperature of 450° C. without applied stress, two bars of each steel being withdrawn, after soaking for the time intervals recorded in Table III., and allowed to cool in air. Izod impact test-pieces prepared from the centre of the respective bars gave the mean results indicated in Table III., the percentage change in

TABLE III.—*Series I., Section* 1.—*Samples Unstressed. Effect of Time of Soaking at* 450° *C. on the Izod Impact Value.*

Mark.	Mean Izod Value. Ft. lb.								
Soaking Time. Hr. :	0	15	24	107	150	192	264	408	844
B1 .	72	68	67	68	61	61	61	63	58
C .	67	53	50	49	51	51	51	50	47·5
D .	72	70·5	69	70	70	70	71	75	64
H .	65	58	53	55	57	56	58	57	27
J .	78	73	69	63	57	58	48	36	16·5
L .	64	60	58	51	48	49	49	46	41
NC .	69	18	12	5	5	3	3	4	3·5
P .	56	50	47	46	45	46	45	39	24
R .	74	60	56	20	17	...	12	10	7·5
S .	56	29	19	5	4	6	4	2	4
T .	42	37	34	18	17	14	14	13	6
W .	63	...	54	...	50	...	...	47	36

impact value being shown graphically in Fig. 1. These results show that four of the steels, *i.e.*, *NC*, *R*, *S*, and *T*, definitely separated themselves from the others in the early stages of the test by showing pronounced embrittlement. Steel *NC* was a nickel-chromium steel known to be temper-brittle, whilst *R*, *S*, and *T* were nickel-

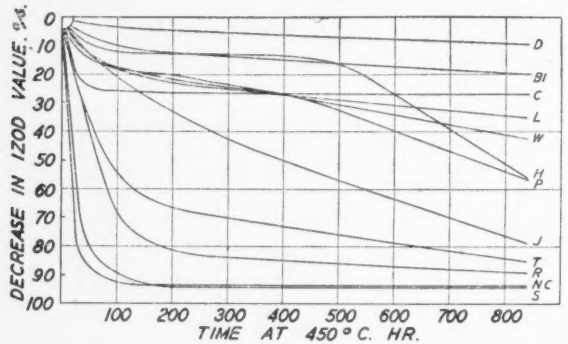


FIG. 1.—Embrittlement Tests at 450° C. Series I., Section 1. No applied stress.

chromium-molybdenum steels containing approximately 1·0% of molybdenum, with the nickel ranging from 2·76 to 5·31%.

Steels *H*, *J*, *P*, and *W* maintained higher impact values than the four previously cited, but the toughness decreased rapidly to comparatively low figures after soaking for 844 hr. The first two of these steels were also nickel-chromium-molybdenum steels, but

containing smaller amounts of the alloying elements than those previously referred to. Steel *P* was a chromium-tungsten-molybdenum steel containing no nickel, whilst steel *W* was a 4·5% nickel-molybdenum steel containing no chromium, and the slope of the curves for these two steels indicated that the toughness might be appreciably reduced if they were maintained at 450° C. for a longer period. The remaining four steels *B*1, *C*, *D*, and *L* maintained still higher Izod values even after 844 hr. at 450° C., steels *B*1 and *C* showing appreciably greater resistance to embrittlement than steel *R*, which was similar as regards initial tensile and impact strength, but contained approximately 2·0% more nickel.

It appeared from the foregoing results, therefore, that a mildly alloyed steel of the type *D*, containing no nickel, possessed pronounced resistance to embrittlement; that the higher the total alloy content of the steel, excluding molybdenum, the greater must be the percentage of molybdenum to ensure relative freedom from embrittlement; and that for the types of steels examined a high nickel content, particularly in the presence of chromium, might have a deleterious influence. This latter indication is, in part, confirmed by the results obtained by other investigators [1-2] and is clarified by reference to Table IV.

TABLE IV.—*The Influence of Increasing Nickel Content in Nickel-Chromium-Molybdenum Steels.*

Mark.	Ni. %	Cr. %	Mo. %	Izod Value. Ft. lb.	
				Initial.	After 844 Hr. at 450° C.
D	0·04	0·64	0·40	72	64
*B*1	0·96	0·97	0·81	72	56
C	0·68	0·83	1·12	67	47·5
R	2·76	1·05	0·98	74	7·5
J	2·58	0·62	0·68	78	16·5
H	3·32	0·77	0·24	65	27*
S	4·19	1·02	0·93	56	4
T	5·31	0·55	1·54	42	6
W	4·58	0·06	0·52	63	36*

* Still decreasing fairly quickly after 800 hr.

SERIES I., SECTION 2.—THE EFFECT OF APPLIED STRESS.

Samples of the same steels as those investigated in Section 1 were also subjected to a constant temperature of 450° C., but a tensile stress of 11·0 tons per sq. in. was applied to the pieces, in the cold state, in such a manner that the stress would remain approximately 11·0 tons per sq. in. at 450° C., except as modified by any slight "creep" taking place. The method adopted for stress application purposes is shown in the photograph Fig. 8 (Plate XXX.),

the stress being applied by upward rotation of the ring *A* screwed on to the centre bar *B*. The stress was thus transmitted from the upper disc to disc *C* through the side links, and was calculated from the measured extension between the inner surfaces of the

TABLE V.—*Series I., Section 2.—11·0 Tons per sq. in. Tensile Stress Applied. Effect of Time of Soaking at 450° C. on the Izod Impact Values.*

Mark.	Mean Izod Value. Ft. lb.			
Soaking Time. Hr.:	0	150	408	844
B1	72	59	59	57
C	67	46·5	43	43
D	72	69	68	66
H	65	44	39·5	28
J	78	62	30·5	13
L	64	48	45	43
NC	69	3	3·5	2
P	56	43·5	40	32
R	74	12	5	7·5
S	56	8·5	6	3
T	42	12·5	7·5	10
W	63	51·5	38	30

discs *C* and *D*, and also by extensometer measurements on suitably disposed test samples incorporated in the assembly. Three such assemblies of test samples were charged into the furnace together,

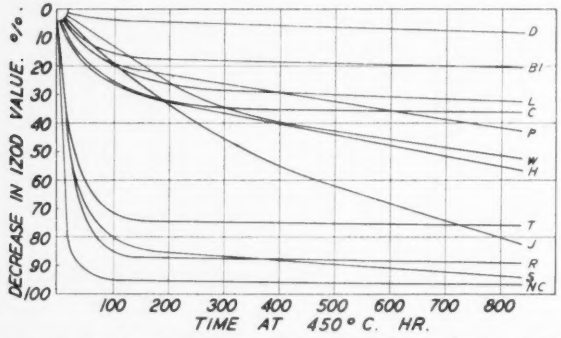


FIG. 2.—Embrittlement Tests at 450° C. Series I., Section 2. Applied tensile stress 11·0 tons per sq. in.

one being removed after 150 hr., one after 408 hr., and the last assembly after 844 hr. at 450° C. Each batch was air-cooled after withdrawal from the furnace, and two-notch Izod test-pieces were

machined from the centre of each sample. The mean Izod impact figures are included in Table V., the decrease in toughness being plotted in Fig. 2. From the latter figure it is apparent that the general trend of the curves is very similar to that of the respective unstressed samples shown in Fig. 1, the steels also being placed in approximately the same order with regard to their resistance to embrittlement after soaking for 844 hr. After this period the impact results obtained on stressed and on unstressed samples were practically the same in all cases, hence it was apparent that the presence of a constantly applied tensile stress of 11·0 tons per sq. in. in the steels, whilst they were maintained at 450° C. for 844 hr., did not induce any more embrittlement than was obtained in the unstressed materials subjected to similar thermal conditions. Recent work by other investigators [2] has shown that slowly repeated stresses might reduce the resistance to embrittlement at elevated temperatures.

Series I., Section 3.—The Effect of Intermittent Heating and Cooling.

For this section of the investigation, samples of seven steels were placed in the furnace and heated to 450° C. This temperature was maintained for approximately 7½ hr., after which the samples were allowed to cool in the furnace to 100° C. They were then reheated to 450° C., and the previous procedure was repeated. Samples of each steel were removed after 100, 200, and 300 hr. at

Table VI.—*Series I., Section 3.—The Effect on the Izod Values of Intermittent Cooling from and Reheating to 450° C.*

Mark.	Initial Izod Value. Ft. lb.	Izod Impact Value (with Intermittent Cooling). Ft. lb.			Izod Impact Value (without Intermittent Cooling). Ft. lb.		
No. of Hours at 450° C.:		100	200	300	100	200	300
*B*1 . .	72	69	62	63	64·5	63	62
C . .	67	59	51	54	50	49·5	49
D . .	72	68·5	66	78	69·5	68·5	68
H . .	65	62·5	55	54	57	56·5	56·5
L . .	64	62·5	49	53	52·5	49·5	48
NC . .	69	20·5	4·5	4·5	5	4	4
W . .	63	59	52	53	50	49·5	42

450° C., excluding the time required for 17, 31, and 45 heating and cooling periods respectively. The Izod impact values obtained on the seven steels after the three periods are tabulated in Table VI., the values for the same steels continuously maintained at 450° C. for 100, 200, and 300 hr. being also included for comparison purposes.

The evidence indicated that a gradual decrease in impact value

took place in all the steels, except steel *NC*, within the first 200 hr.; it then remained fairly constant up to 300 hr. at 450° C. Steel *D* gave an increase of 10 ft. lb. at the end of the 300-hr. period, but microscopical examination of the samples after testing for 300 hr. showed that they contained segregated areas of free ferrite, the quantity of ferrite in those areas being much more pronounced than in the other samples of the material. It is probable that the increased impact values obtained on those samples were due to this segregated ferrite, and not to the effect of intermittent heating and cooling. Comparison of the impact figures obtained on the samples main-

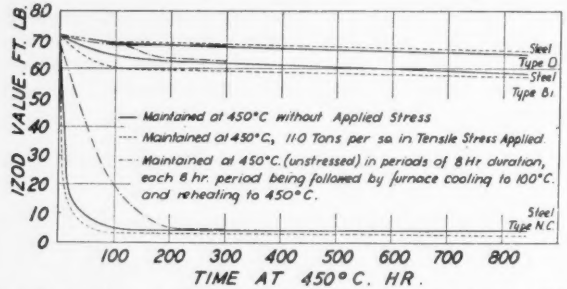


FIG. 3.—Embrittlement Tests at 450° C. Series I., Section 3. Effect of stress on intermittent temperature changes.

tained at 450° C. for 300 hr. with those obtained after the 300-hr. period with intermittent heating and cooling indicated that periods of heating and cooling had no further effect on the resistance of the steels to embrittlement other than would be observed on similar samples continuously maintained at the elevated temperature. The results of the experiments in Series I., Sections 1, 2, and 3, therefore, indicated that neither an applied stress of 11·0 tons per sq. in. at 450° C., nor intermittent coolings from and reheatings to that temperature materially influenced the embrittlement of the steels. This conclusion is illustrated by Fig. 3.

SERIES II.

The first series of experiments indicated certain types of steel which showed much greater resistance to embrittlement than others. Accordingly a second series of experiments was carried out on steels similar in composition to those of the first series, but from different casts, the aim of this portion of the investigation being to ascertain whether the embrittlement at 450° C. was entirely a question of chemical composition, or whether the manufacturing processes had any bearing on the results. Thirteen steels were chosen for these experiments, the analyses, heat treatments, and

mechanical properties of which are given in Tables I. and II. The experimental procedure was exactly the same as that described for Series I., Section 1, the soaking time at 450° C. occupying a total period of 850 hr. The mean impact values obtained after various

TABLE VII.—*Mean Izod Values after Maintaining at 450° C.—Series II.*

Mark.	Mean Izod Impact Value. Ft. lb.					
Soaking time. Hr.:	0	24	100	300	600	850
A . . .	68	70	66	60	55	42
B . . .	78	76	77	77	63	57
*C*1 . . .	72	69	66	60	43	40
*E*1 . . .	50	44	43	41	53	46
F . . .	58	53	52	54	55	55
G . . .	67	63	63	63	59	55
K . . .	54	49	55	48	47	43
M . . .	52	44	43	34	33	27
NC(Ex.) .	16	11	3	3	4	4
N . . .	40	36	27	16	12	11
O . . .	49	38	34	26	24	24
U . . .	38	35	32	13	9	9
V . . .	38	38	32	12	6	8

soaking times are recorded in Table VII., the change in toughness being plotted in Fig. 4. The results obtained on steels *E*1, *F*, *N*, *NC*(Ex.), *O*, *U*, and *V* confirmed those obtained on the similar steels

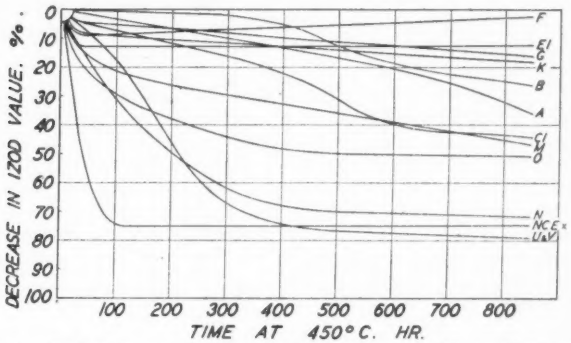


FIG. 4.—Embrittlement Tests at 450° C. Series II. No applied stress.

tested in Series I., Section 1. However, the shape of the curves for steels *A*, *B*, and *C*1 differed appreciably from those indicated in Fig. 1 for the similar steels *B*1 and *C*. Also, in Series I., Section 1, steels *H*, *J*, and *L* gave results which were not confirmed by the

subsequent tests on similar steels *G*, *K*, and *M*, respectively. It was considered that some of these apparent irregularities might have been due to some softening of the samples during the soaking, or to changes in the microstructure, but the Brinell hardness tests recorded in Table VIII. indicated that no softening had taken place, whilst metallographic examination revealed no structural alterations. The evidence obtained on certain of the steels was, therefore, some-

TABLE VIII.—*Brinell Hardness Numbers before and after Soaking at 450° C.*

Series I. and II.						Series III.		
Mark.	Brinell Number.		Mark.	Brinell Number.		Mark.	Brinell Number.	
	Initial.	After Soaking for 844 Hr.		Initial.	After Soaking for 844 Hr.		Initial.	After Soaking for 2400 Hr.
A	321	321	*M*	331	326	*A*	311	306
B	321	311	*NC*	269	269	*B*	306	306
*B*1	269	269	*NC*(Ex.)	321	301	*C*	277	273
C	277	277	*N*	321	321	*D*	286	277
*C*1	321	321	*O*	321	321	*E*	286	286
D	248	248	*P*	262	262	*F*	302	302
*E*1	321	321	*R*	269	269	*G*	306	306
F	311	306	*S*	293	293	*H*	302	298
G	311	306	*T*	302	302	*J*	298	298
H	277	277	*U*	311	301	*K*	311	306
J	269	269	*V*	311	293	*L*	282	282
K	321	321	*W*	277	277	*M*	321	316
L	289	286						

what disconcerting, and a third series of experiments was carried out with a threefold object in view : First to determine whether the results could be repeated on certain of the steels—that is, to determine whether some unaccountable deviation in the experimental procedure had been responsible for the apparent irregularities; secondly, to determine whether the variable results were due to differences in the manufacturing processes, or applied heat treatments; and thirdly, to ascertain the extent of the embrittlement after a much longer soaking time at 450° C.

SERIES III.

For this portion of the investigation, the following steels were chosen : Steels *C*, *D*, *H*, *J*, and *L*, which had previously been tested in Series I.; steels *A*, *B*, *F*, *G*, *K*, and *M*, which had been included in Series II.; and steel *E*, which was similar in composition to steels *D* and *F*. Thus five classes of steel were investigated,

steels *A*, *B*, and *C* being of the 1% nickel, 1% chromium, 1% molybdenum type; *D*, *E*, and *F* were steels containing approximately 0·6% of chromium and 0·5% of molybdenum; *G* and *H* contained approximately 3·5% of nickel, 0·7% of chromium, and 0·25% of molybdenum, and steels *J*, *K*, *L*, and *M* contained approximately 2·5% of nickel, 0·6% of chromium, and 0·6% of molybdenum. The heat treatments and initial mechanical properties of the steels for this series are shown in Table IX., the effect of soaking time up to

TABLE IX.—*Heat Treatment and Mechanical Properties.—Series III.*

Mark.	Heat Treatment.	Yield Point. Tons per sq. in.	Maximum Strength. Tons per sq. in.	Elongation. %	Reduction of Area. %	Izod Value. Ft. lb.
A	O.H. 850° C. T. 655° C.	59·76	66·4	21·2	63·3	66
B	O.H. 850° C. T. 640° C.	60·2	64·6	21·2	66·4	74
C	O.H. 850° C. T. 680° C.	55·9	60·0	22·5	64·0	63
D	W.H. 850° C. T. 575° C.	52·4	59·3	19·5	60·6	57·5
E	W.H. 875° C. T. 620° C.	55·4	61·16	22·0	66·4	68·5
F	W.H. 850° C. T. 610° C.	58·5	64·0	21·0	62·6	57
G	O.H. 850° C. T. 605–610° C.	60·6	66·0	22·0	64·3	70
H	O.H. 830° C. T. 585° C.	59·25	64·4	23·5	65·0	59·5
J	O.H. 830° C. T. 640° C.	58·0	63·9	22·0	65·3	72
K	O.H. 850° C. T. 630° C.	59·3	65·8	22·2	64·3	62·5
L	O.H. 830° C. T. 685° C.	49·5	62·5	23·0	57·2	65
M	O.H. 850° C. T. 650° C.	63·6	70·9	20·5	58·4	51

2400 hr. at 450° C. on the Izod values being indicated in Table X. and Fig. 5. Up to 850 hr., the results agreed quite well with those previously obtained on the same steels in Series I. and Series II.,

TABLE X.—*Mean Izod Values after Maintaining Steels at 450° C.—Series III.*

Mark.	Mean Izod Impact Value. Ft. lb.							
Soaking time. Hr.:	0	24	300	450	850	1200	1800	2400
A . . .	66	62	59	52	39	30	24	18
B . . .	74	74	74	66	52	45	35	21
C . . .	63	59	57	59	55	54	52	51·5
D . . .	57·5	57·5	57	56	56	53	61	55
E . . .	68·5	66·5	70	69	65	71	72	71
F . . .	57	56	56	53	56	55	53	52
G . . .	70	67	...	56·5	50	52	40	28
H . . .	59·5	53	...	27	26	22	20	13·5
J . . .	72	60	31	18	14	11	9	6
K . . .	62·5	61	51	53	39	32·5	27	21·5
L . . .	65	61	51	50	45·5	43	42·5	40
M . . .	51	45	43	36·5	29	29	23	19

indicating that variations in experimental procedure had not produced the variable results encountered during the testing of some similar types of steels. Samples were soaked, therefore, in the fur-

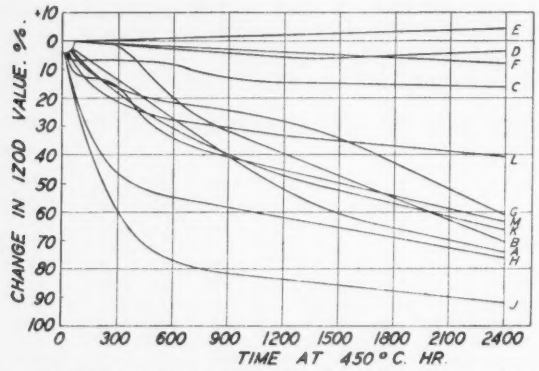


FIG. 5.—Embrittlement Tests at 450° C. Series III. No applied stress.

nace for a further 1200, 1800, and 2400 hr. and tested in the usual manner after air-cooling from 450° C.

The general indications from the results given in Table X. and Fig. 5 were :

(*a*) A comparison of the impact results on the following steels : Steels *C* with steels *A* and *B*, steel *E* with steels *D* and *F*, steel *G* with steel *H*, and steel *L* with steel *M*, indicated that when comparing steels of similar chemical composition, hardened in the form of bars of the same diameter, the samples tempered at the higher temperature showed greater resistance to embrittlement at 450° C.

(*b*) One type of steel gave consistently good resistance to embrittlement, *viz.*, steel typified by *D*, *E*, and *F*.

(*c*) Steel of the class represented by *A*, *B*, and *C* was capable of giving good results, but the resistance to embrittlement might be influenced to an appreciable extent by the tempering treatment after hardening.

(*d*) The remaining pairs of steels, *G* and *H*, *J* and *K*, *L* and *M*, all containing higher total additions of nickel and chromium than the others, with varying amounts of molybdenum also present, suffered appreciable embrittlement after 2400 hr. at 450° C., the heat treatment process again apparently having some influence. Comparison of the results on steels *L* and *M* with those on similar steels *J* and *K* indicated that with steels of this type an increase in the carbon content from 0·30 to

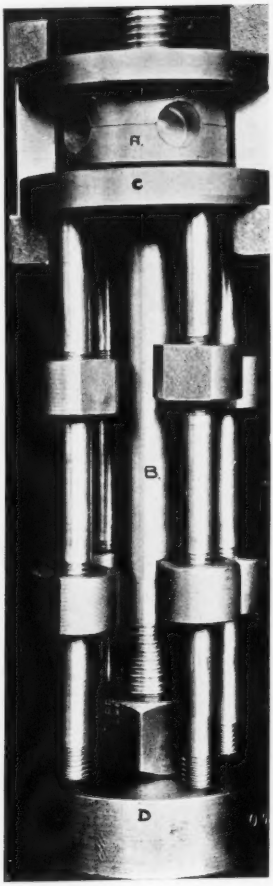
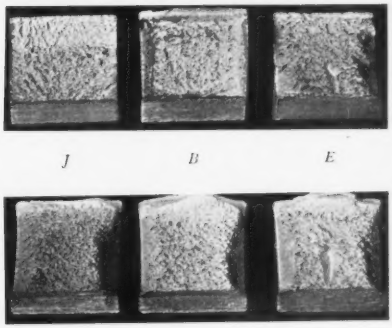
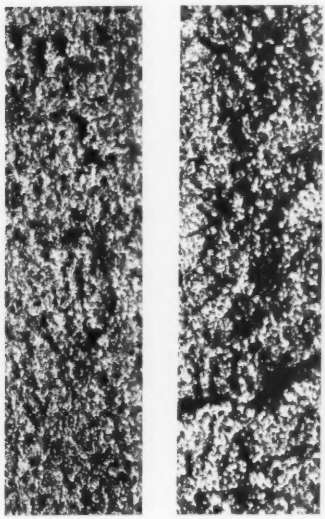


FIG. 8.—Assembly for Applying Stress simultaneously to twelve test lengths.



Top Row: After 2400 hr. at 450° C.
Bottom Row: As heat-treated.

FIG. 9.—Nickel-Chromium-Molybdenum Steels *J* and *B* and Chromium-Molybdenum Steel *E*. Fractures of Izod test-pieces. × 1·65.



(*a*) (*b*)

(*a*) As heat-treated.
(*b*) After 2400 hr. at 450° C.

FIG. 10.—Fractures of Izod Test-Pieces of Steel *J*, showing coarser and intercrystalline nature of the fracture of the embrittled material. × 20.

Goodrich.

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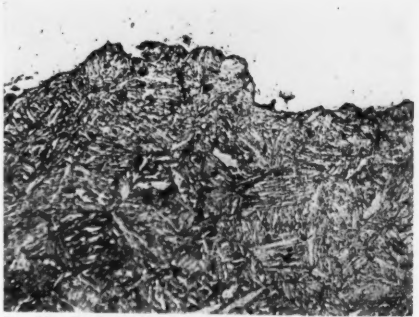

FIG. 11.—Steel *J* as heat-treated, depicting transcrystalline contour of the fracture. × 500.

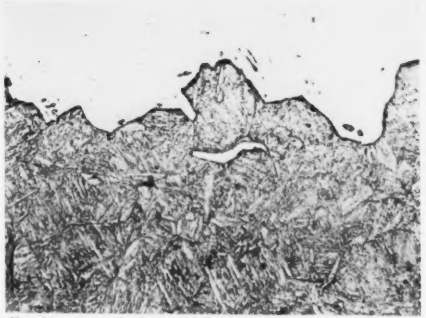

FIG. 12.—Steel *J* after 2400 hr. at 450° C.; path of fracture partly intercrystalline. × 500.

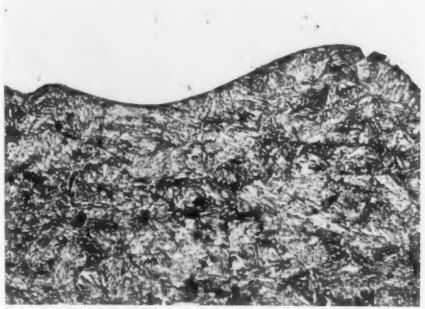

FIG. 13.—Steel *B* as heat-treated, depicting transcrystalline contour of fracture. × 500.

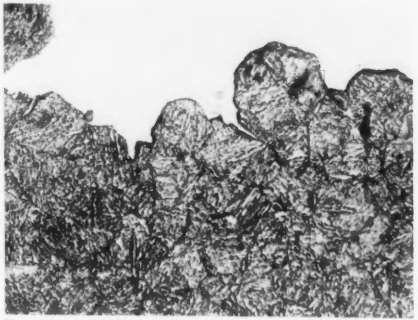

FIG. 14.—Steel *B* after 2400 hr. at 450° C., showing partly intercrystalline nature of fracture. ×500.

(Micrographs reduced to four-fifths linear in reproduction.)

[*To face p.* 361 P.

0·45% proved beneficial, presumably because the higher percentage of carbon permitted the use of a higher tempering temperature to attain the requisite tensile strength.

(*e*) Brinell hardness values determined on the twelve steels before soaking and also after 2400 hr. soaking at 450° C., the results being included in Table VIII., showed no marked change.

Microscopical Examination of the Samples of Series III.—All the Izod samples prepared from bars which had become embrittled by soaking for 2400 hr. at 450° C. exhibited more or less marked intercrystalline fractures. Three pairs of fractures from samples *J*, *B*, and *E* were examined at a magnification of 20 diameters, each pair consisting of a fractured sample not subjected to the 450° C. treatment and one sample subjected to 2400 hr. at 450°C. The actual fractures are indicated in Fig. 9 (Plate XXX.), whilst the fractures of the respective samples of steel *J* at a magnification of 20 diameters are shown in Fig. 10. The fractures from steels *J* and *B* after embrittlement differed appreciably from those obtained on samples not subjected to 450° C., being coarser and distinctly crystalline. The two fractures from steel *E* showed no visible difference. In order to confirm that the fractures of the embrittled samples of *J* and *B* were intercrystalline, microsections were prepared from two Izod fractures of each steel to include the edge of the fracture, the fractures themselves being copper-plated. Subsequent metallographic examination indicated that in the case of the samples not subjected to treatment at 450° C. the fractures were transcrystalline, whilst the fractures of the samples subjected to 450° C. for 2400 hr. were partly intercrystalline. Figs. 11 to 14 (Plate XXXI.) show the appearance of the respective fractures at high magnification. Even after 2400 hr. at 450° C., the steel *E*, however, fractured in a transcrystalline manner. In order to detect any change in the formation of the micro-constituents likely to have caused this difference in the type of fracture, etched sections of the various steels were examined at magnifications up to 1400 diameters, but no definite evidence was obtained to account for the partly intercrystalline nature of the fractures of the embrittled samples.

Series IV.—Strain-Age-Embrittlement Tests.

In the foregoing part of this contribution, an attempt has been made to indicate the effects of time of soaking, constantly applied stress, and temperature fluctuations on the resistance to embrittlement at 450° C. of a number of types of high-tensile alloy steel. It has been demonstrated by earlier investigations [3] that initial strain applied to certain low-tensile steels results in an intensification of the embrittlement when such steels are maintained at elevated temperatures after straining. However, there are very few

published data regarding strain-age-embrittlement in high-tensile steels, and since this is a condition frequently arising in structures working at elevated temperatures some experimental evidence on the embrittlement of strained materials of this class was considered desirable.

Accordingly, four steels of analyses given in Table I. were heat-treated in the form of $1\frac{1}{8}$ in. dia. bars, the heat treatments and resultant mechanical properties being recorded in Table XI.

TABLE XI.—*Heat Treatment and Initial Mechanical Properties of Steels for Series IV.*

Mark.	Heat Treatment.	Yield Point. Tons per sq. in.	Maximum Strength. Tons per sq. in.	Elongation on 2 in. %.	Reduction of Area. %.	Izod Value. Ft. lb.
A .	O.Q. 850° C. T. 655° C.	61·4	67·4	21·5	62·6	68, 77
E .	W.Q. 875° C. T. 620° C.	56·6	62·7	22·0	62·2	67, 66
L .	O.Q. 830° C. T. 685° C.	53·3	63·0	22·0	58·4	65, 60
KI .	O.Q. 830° C. T. 640° C.	56·6	63·8	22·8	64·0	65, 63

After heat treatment the bars were machined to 0·8 in. dia., a selection from each batch being strained in tension by 2·5% and 5·0%, measured on a 4·0 in. gauge length. Unstrained and strained samples of each steel were then maintained either at 200° C. for

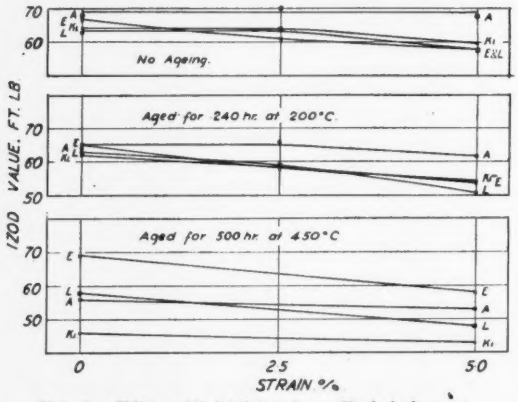

FIG. 6.—Effect of Initial Strain on Embrittlement.

periods of up to 240 hr., or at 450° C. for periods of up to 500 hr., samples of each steel in the strained and the unstrained condition being withdrawn from the furnace after the desired time interval, and

air-cooled. Izod impact tests were then conducted on standard 10 mm. square sections machined from the centre of each bar, the resultant values being embodied in Figs. 6 and 7.

Reference to the series of curves included in Fig. 6 reveals that an appreciable amount of permanent strain resulted in a very small decrease in the impact values of the unaged steels, which

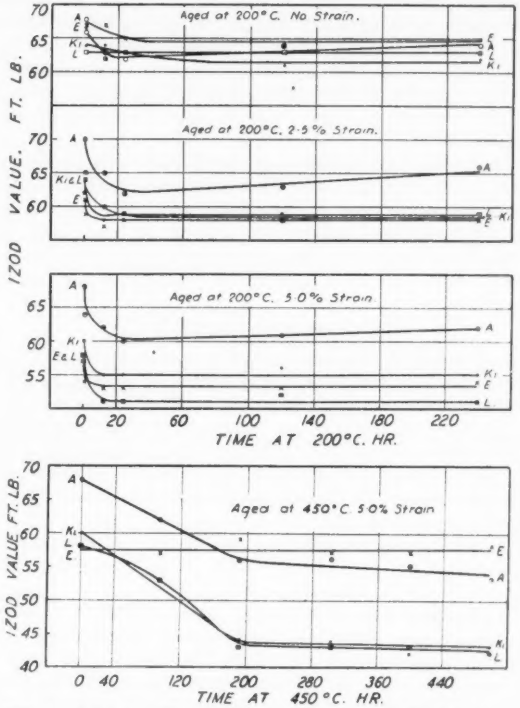
Aged at 200°C. No Strain.
Aged at 200°C. 2·5% Strain.
Aged at 200°C. 5·0% Strain.
IZOD VALUE. FT. LB.
TIME AT 200°C. HR.
Aged at 450°C 5·0% Strain
IZOD VALUE FT. LB.
TIME AT 450°C. HR.

FIG. 7.—Effect of Ageing Time and Temperature on Embrittlement after Straining.

decrease was only slightly more pronounced after ageing for 240 hr. at 200° C., or after 500 hr. at 450° C. The resistance to embrittlement, therefore, appeared to be almost uninfluenced by the amount of permanent strain applied to the high-tensile steels investigated.

The effect of time at the ageing temperatures is depicted by the families of curves plotted in Fig. 7. These indicate that approximately 24 hr. ageing at 200° C. was required for strained material, to lower the Izod values to the minimum for each steel, after which

period ageing had no significant effect. The application of 5% permanent strain appeared to have slightly increased the embrittlement recorded during the first 24 hr. ageing, but steels *E* and *A* showed an increase in toughness when the ageing time was further increased. When an ageing temperature of 450° C. was adopted, however, strain-age-embrittlement was more in evidence. The chromium-molybdenum steel *E* was the only one which showed no fall in impact value after 500 hr. at the ageing temperature, whilst steel *A* proved to be only slightly inferior after exhibiting a fairly rapid decrease in toughness in the first 200 hr. The remaining steels *KI* and *L* showed more pronounced embrittlement during the first 200 hr., after which an Izod value of approximately 42 ft. lb., was maintained.

Comparison of the effects of ageing at 200° C. with those induced by ageing at 450° C. indicate that, with the exception of the chromium-molybdenum steel *E*, more pronounced embrittlement was obtained at the higher temperature, and a longer period was required before the first stages of comparatively rapid embrittlement were completed.

Summary and Conclusions.

Twenty-seven high-tensile alloy steels comprising eleven different types have been tested to find the effect of soaking at 200° C. and at 450° C. for various periods of up to 2400 hr. The effects of a constantly applied stress of 11 tons per sq. in. during the soaking period, of intermittent temperature fluctuations from 450° C. to 100° C., and of the presence of initial permanent strain, have also been investigated. The results have indicated that the following conclusions are permissible :

(1) A mildly alloyed steel of the type *D*, containing approximately 0·6% of chromium and 0·5% of molybdenum, yielded the greatest resistance to embrittlement.

(2) The higher the total nickel and chromium content of the steels, the greater was the molybdenum percentage apparently necessary to ensure relative freedom from embrittlement.

(3) An increase in the nickel content appeared to decrease the resistance to embrittlement of steels containing chromium and molybdenum.

(4) The embrittlement effects were uninfluenced by the presence of an applied tensile stress of 11 tons per sq. in., or by intermittent slow cooling from and reheating to 450° C.

(5) When comparing steels of practically the same composition, samples tempered at the highest temperature yielded the greatest resistance to embrittlement at 450° C.

(6) All the samples embrittled after heating for 2400 hr. at 450° C. exhibited a more or less temper-brittle impact fracture, the path of the fracture being partly intercrystalline.

(7) Soaking for 2400 hr. at 450° C. had no marked influence on the Brinell hardness values of the steels.

(8) The amount of embrittlement was almost uninfluenced by the presence of permanent strain up to 5·0%.

(9) Approximately 24 hr. was required at an ageing temperature of 200° C. to reduce the impact value to the minimum level obtained during the tests; at 450° C. this time period was increased to 200 hr., after which further embrittlement might take place at a very much slower rate.

(10) Embrittlement was more pronounced at 450° C. than at 200° C., except in the case of a steel of the chromium-molybdenum type *D*.

This investigation was carried out at the request of the Directors of The English Steel Corporation, Limited, and the author wishes to express his thanks to them for granting permission to publish the foregoing data, also to Mr. H. H. Burton for his suggestions and useful criticisms, and to those members of his staff who have rendered assistance in the experimental work.

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(3) P. Goerens: *Zeitschrift des Vereines deutscher Ingenieure*, 1924, vol. 68, Jan. 19, pp. 41–47.

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DISCUSSION.

Dr. W. H. HATFIELD, F.R.S. (Vice-President, Sheffield), said he had read the paper with very great interest. It dealt with one subject which was of the greatest importance to engineers at the present time, when the question of high-temperature boiler practice was being considered. One found in the paper evidence in a measure of the kind that one would expect, but he felt that the paper would have been of much greater value had the author given a little more weight to other factors than composition.

In Table I. the analyses were given, and in Table II. the original treatments accorded to the steels. The treatments specified in Table II. included oil-hardening from 830° C. and tempering to 650° C. The time-temperature effect both as regards hardening and as regards tempering was of the greatest importance, and it was essential to know, for instance, how long the steels were at the tempering temperature, and whether they were slowly or quickly cooled from that tempering temperature ; so that on that basis alone the evidence derived from the author's very interesting long-time tests rather lost value.

Again, the analyses of the steels were given, but the process by which the steels were made was not stated. Were they electric steels, were they acid open-hearth steels, or were they basic steels ? Had the physical chemistry reactions in the furnace at the time the steels were made been taken to that critical position which was known to be essential in the production of highest quality steels ?

He suggested to the author that a bald statement with regard to composition and typical treatment did not provide sufficient data with which seriously to correlate the results. The Institute was very much indebted to the author and his firm for bringing forward the results of the effect of long periods of time up to 2000 hr. on these steels, but, when he considered the results in detail, and compared them with his own figures, he found that the deductions which the author made were not quite the same as those which he himself was able to draw. For example, it would be surmised from the paper that the presence of a substantial nickel content in a nickel-chromium-molybdenum steel disqualified that steel for serious use at superheated steam temperatures, but that was not the case. It might be of interest to mention that the firm with which he was associated manufactured a very considerable tonnage of fairly high nickel-chromium-molybdenum steels in the electric furnace, under the ideal reducing conditions obtainable with the electric furnace, and in a number of instances they had been able to examine bolts, for instance, of that material before and after long service under conditions of temperature of 400° C., 450° C., and so on, and there had been no serious depreciation in the Izod impact value, and in fact in certain cases no depreciation at all. In a

similar set of experiments over a somewhat shorter period of time, but over hundreds of hours, it was clearly demonstrated that the conditions of manufacture in the furnace and the actual conditions governing the tempering operations were almost as dominating as the actual composition of the steel, if not more so. It was to be regretted that in the present case the author had left out of consideration any serious statement on those points.

One would infer from the paper also that chromium-molybdenum steels were the ideal steels for high temperature practice. He could almost hear a suggestion for manganese-molybdenum. In other words, there seemed to be an idea that it was desirable to get away from the 3% nickel, 0·75% chromium, 0·6% molybdenum steels. He thought it would be rather a pity to depart from an established practice, a practice in which most important engineering organisations were involved, on the basis of the somewhat scanty and piecemeal evidence brought forward in the form of papers. He would not characterise the present paper in that way, but he had in mind other papers which had had to be considered recently.

He thought that the real test and the only test of the utility of steels for these special purposes was the test under service conditions, and there was now an accumulating mass of evidence where the steels had actually been examined previous to service and after three, four, five, six and more years. A considerable amount of useful data had also been accumulated with regard to small reaction chambers for chemical plant work, and the data there could be related to that put forward by the author.

To show how undesirable it was that too hasty conclusions should be drawn with regard to the influence of nickel for high temperature work, he would give the result of one experiment. A 0·34% carbon, 3·40% nickel steel was exposed for 336 hr. at a temperature of 500° C. Before the experiment, the Izod values were 80, 80, 84; after the experiment, they were 75, 81, 88. That established that it was not intrinsically the nickel which was responsible for the results under discussion.

He would like to congratulate the author on a very good piece of work, but he hoped he had said enough to emphasise that the reactions in the furnace as influencing the characteristics of the steel, the details of the heat treatment, and the composition other than the essential elements required very careful consideration, comparison and full statement before conclusions such as the author would presume to deduce could be drawn.

Mr. T. Henry Turner (Doncaster) said the paper might alarm anyone who was using one of the twenty-seven alloy steels to which the author referred; so many alloys might make one feel that the subject must have been completely covered. Personally, however, he did not think that there was so much reason for alarm as might appear. If the author would add to the figures already given similar

figures for an ordinary good mild steel, a normal boiler steel, a straight nickel steel with no chromium, and perhaps the ordinary 3½% nickel steel, a better idea would be given of how to judge the figures. Engineers at present were confused by a mass of embrittlements; there were so many ways, apparently, in which steel could become brittle. To begin with, the engineer was worried at the moment about the so-called caustic embrittlement. According to the latest information from the United States of America, instead of calling it caustic embrittlement one must look for the effect of silica, silica in the feed-water having apparently more to do with the results than any of the caustic alkalis. Then there was temper-brittleness with the nickel-chromium steels, and black-brittleness, and season cracking, and the cracking of hot metals by tinning, apart altogether from the ordinary fatigue cracking. To all of those it was necessary to add, apparently, one other form of cracking; it seemed that if one merely heated any form of alloy steel it would become embrittled at 200° C. or 450° C. He would like to know whether that was the picture which the author really wished to present. Was a designer to have no steam-engine bolt made of any alloy steel other than the low-carbon chromium-molybdenum steels, because the temperature might be 200° C. or 450° C.? Was every turbine to be held down by some other material than an alloy bolt?

The real question, if all these steels were brittle, was which was the villain of the piece. Was it the nickel, the chromium, the molybdenum, or what was it? So far as the author's analyses went, it would be seen that the three steels with no nickel in them at all could become brittle, sufficient proof that at any rate the nickel was not the only villain in the piece and that some of the other elements might be responsible. Was it higher carbon? A low carbon content was recommended. It was really suggested in the paper that the trouble was purely a heat-treatment effect. The effects of the atmosphere seemed to be exonerated; this was merely a heat-treatment effect, embrittling the steel, apparently, by a grain boundary change, but not producing visible cracks. He would like the author to confirm the fact that he observed no visible cracks, such as might be seen in a so-called "caustic embrittled" boiler plate.

If it was purely a heat-treatment effect, that suggested that the point of interest was a precipitation, presumably of carbide. Nickel might be pictured as going into solid solution in the ordinary way, and the chromium as producing carbides; and that might fit in with the fact that the nickel-free steels were still embrittled. So far as his own experience was concerned, the only embrittled nickel steel bolts which he had examined had all had obvious bad heat treatment, and those who knew the practice in works in the past would realise that many such bolts had very irregular kinds of heat treatment, in open fires, and not by any means the type of heat

treatment which one associated with automobile and aircraft practice.

Turning to another feature, the strains and the stresses seemed to be exonerated, which was surprising; one would have thought that it was the constant stress which was encouraging these changes. No change was visible in grain size. That was distinctly interesting, because whenever one found an embrittled bolt with a bad grain size one could now blame the manufacturer for having put it in in that condition.

Finally, he would like to ask the author to say whether there was any truth in the statement that of two steels with similar analyses—chemical, not necessarily spectrographic—coming from different makers, with different heat treatments, one would embrittle rapidly, and the other, so far as commercial practice went, would never embrittle.

Dr. T. SWINDEN (Member of Council, Stocksbridge) remarked that his first introduction to the subject under discussion was in 1929, when Mr. R. W. Bailey, of Metropolitan Vickers, showed him some of the results which were afterwards published before the Institution of Mechanical Engineers. So far as he could recall those early results, the common factor in the steels which did cause embrittlement was nickel. Whether or not that was the whole story was another matter, but it struck him then that, if the nickel was suspect, there was no reason to worry about it. He was associated at that time with some research on the various modifications of the chromium steels, and it was decided to adopt the chromium-molybdenum steels for two reasons. First, it was quickly proved that with sufficient molybdenum the embrittlement effect in question was completely suppressed; secondly, the molybdenum was the most useful constituent for raising the creep resistance.

Some five or six years ago, therefore, his company standardised the chromium-molybdenum steel, and they had now had the sort of experience which Dr. Hatfield had referred to as being necessary, namely, that in actual practice bolts had been in steaming service for nearly 20,000 hr., and complete freedom from embrittlement had been achieved. In general, therefore, he was in agreement with the main conclusions of the paper; and, since all the desirable mechanical properties could be obtained from a chromium-molybdenum steel, and in view of the fact that it was now proved—completely to the speaker's satisfaction—that such a steel was free from embrittlement, it did not seem necessary to look further for another type of steel.

CORRESPONDENCE.

Mr. J. A. JONES (Stocksbridge) wrote that the embrittlement of alloy steels when subjected in service to prolonged exposure at temperatures within the range 350–550° C. had lately become particularly important in view of the trend of power-plant development towards the use of higher steam temperatures and pressures, and the use of alloy steels for the parts which were subject to the most severe conditions. A contribution such as the present paper, which dealt with such a variety of steels so appropriately selected, was particularly valuable.

Freedom from embrittlement in service must be regarded as an essential property of these steels, whilst generally the steels were also required to possess a reasonably high limiting creep stress.

A close relationship must exist between the susceptibility to embrittlement of the type under consideration and susceptibility to temper-brittleness. Unfortunately, service temperatures in these power plants coincided very closely with the range of temperature within which temper-brittleness developed. Thus, any steel known to be susceptible to temper-brittleness could be eliminated immediately from consideration. However, the old criterion for determining susceptibility to temper-brittleness, based on the results of notched-bar impact tests after slow cooling from the tempering temperature, was insufficiently searching in the present instance, although it was pretty evident that they were dealing with the same phenomenon but approaching an extreme.

Evidence was constantly accumulating in support of the view that the presence of stress had little effect on susceptibility to embrittlement, and this was confirmed further by the results now reported.

The results obtained in the Central Research Department of the United Steel Companies, Ltd., confirmed those given by the author, that embrittlement after long exposure at temperature was not accompanied by any change in Brinell hardness.

Time of exposure at temperature was an important factor in estimating the susceptibility of a steel to embrittlement, whilst the actual rate of cooling adopted was an equally important factor in determining susceptibility to temper-brittleness. It was considered that if it were practicable to reduce the rate of cooling from the tempering temperature to such an extent as to render it comparable with the long times of exposure now adopted for estimating susceptibility to long-time embrittlement, similar relations would be found to exist between the notched-bar figures obtained after the two treatments, in the same manner as had been established for shorter times of exposure in the temper-brittle range, with rates of cooling of the order of $\frac{1}{3}$° C. per min. Certain features characteristic of temper-brittleness were revealed prominently in long-time embrittlement tests. Casts of identical analyses might reveal

widely different susceptibilities, nickel-chromium steels being particularly susceptible, whilst a high phosphorus content increased the degree of embrittlement (examples *G* and *H* in the paper illustrated this latter point). Molybdenum had played an important part in eliminating temper-brittleness under practical conditions, and it was also playing its part in the development of steels free from susceptibility to long exposure embrittlement. It would appear, however, that the function of molybdenum generally was to reduce susceptibility rather than to eliminate it. This was particularly true in nickel-chromium steels. The author's experience with nickel-chromium-molybdenum steels was confirmed by the results obtained by the writer and his co-workers. It had been found that although certain casts of low-nickel and high-molybdenum contents might be entirely free from susceptibility to embrittlement, other casts of identical analyses would exhibit embrittlement even after comparatively short periods of exposure at temperature. Eliminating the nickel from the analyses apparently did away with this feature. The chromium-molybdenum steels thus provided material which was particularly free from susceptibility to all forms of embrittlement, the chromium and molybdenum contents being adjusted according to the mechanical properties required.

In the case of stud bolts, these requirements were usually of the order of 65 to 75 tons per sq. in. as far as tensile strength was concerned. It was to be noted that the steels of this class examined by the author required water-quenching to meet these test conditions satisfactorily. It should be pointed out that the water-quenching treatment was not an essential condition for securing complete freedom from susceptibility to embrittlement. By raising the carbon and chromium contents, equally good mechanical properties, combined with complete freedom from long exposure embrittlement, could be secured after oil-hardening and tempering, and these essential properties were accompanied by a high limiting creep stress at the temperatures under consideration. A steel of this type, known as "Durehete," had been developed about six years ago by Messrs. S. Fox & Co., Ltd., for service as stud bolts on superheater and boiler pipe lines. The records of this steel in service had been completely satisfactory. The mechanical properties were quite equal to those obtained in any nickel-chromium-molybdenum steel. A large number of casts of this steel had been made in the open-hearth furnace, and not a single test had shown indications of embrittlement after long exposures at temperatures of 450° to 550° C. Bolts heat-treated to approximately 70 tons per sq. in. tensile strength, with an impact figure of 53 ft.lb., and withdrawn from service after periods of up to 19,180 steaming hours, showed no loss in ductility as measured by percentage elongation or reduction in notched-bar impact figures as compared with the values obtained before service.

It would be realised from the above remarks that the experience

of the firm with which the writer was associated, as regards the embrittlement of high-tensile alloy steels at elevated temperatures, was in full agreement with the conclusion arrived at by the author in his paper.

Dr. M. L. BECKER (Teddington) wrote that the author had examined a large number of steels and had confirmed that, in nearly every instance, soaking at a temperature of 450° C. brought about considerable embrittlement as shown by the notched-bar impact test. With certain types of steel the degree of embrittlement might appear quite alarming, but it should not be overlooked that materials exhibiting brittleness in the notched-bar impact test frequently showed little or no brittleness if unnotched specimens were used or if other types of brittleness tests were employed. The notch brittleness induced by long soaking at 450° C. was therefore perhaps not so serious as might appear on reading the paper. In this connection it might be useful if the author could make a few additional tests on some of the embrittled materials, in order to show whether they fell into the same order of merit and exhibited the same degree of brittleness when the dimensions of the notch and possibly the speed of the blow were varied.

It was disappointing that the author had not been able to go further than to suggest that the embrittlement which he had studied was due to the development of intercrystalline weakness. Presumably, however, such weakness must result from precipitation from solution of some constituent at the grain boundaries. The degree of embrittlement was undoubtedly influenced by the previous heat treatment of the steel, and it would be interesting to know if the author had any evidence to show whether a high-temperature tempering treatment, which was known to favour rapid precipitation throughout the crystal grain, had any beneficial action in reducing grain boundary precipitation and loss of toughness on subsequent exposure at 450° C.

AUTHOR'S REPLY

The AUTHOR replied that he had listened with considerable interest, and no small measure of astonishment, to Dr. Hatfield's contribution to the discussion, and would point out that, in connection with the suggested omissions from Table II. regarding the time of treatment and physical reactions in the furnace, the author was no greater culprit than Dr. Hatfield himself in past publications. Dr. Hatfield would no doubt be well aware that the steels made by the author's company, especially those made in the open-hearth furnace, were thoroughly deoxidised—that was, "killed" in the bath—and it was considered that to take standard products representing material as issued to users was of more importance than to take steels

during the manufacture of which standard practice had not been adopted.

As regards heat treatment, it should be stated that the time at the tempering temperature was never less than one hour, this time having been determined, by years of experience on the size of bars examined, as being quite suitable. The author also expressly stated when reading the paper that the presence of a substantial content of nickel in nickel-chromium-molybdenum steel only disqualified that steel for certain uses at superheated steam temperatures where age-embrittlement was a major consideration.

One of the statements which surprised the author appreciably, in view of Dr. Hatfield's standing, was his remark that it would be a pity to depart from the established engineering practice of using steels of the 3% nickel, 0·75% chromium, 0·6% molybdenum type. The author was sure that Dr. Hatfield fully appreciated that research and development were directed towards improvements in materials, and perhaps it would not be out of place to quote a recent technical journal, which stated that some branches of manufacture suffered from a slow pulse caused by adhering to tradition or to precedent. The author had difficulty in believing that this statement would represent Dr. Hatfield's attitude towards research and development.

Another reason why the type of steel suggested by Dr. Hatfield was not the most suitable for many uses at elevated temperatures, was that its creep-resisting properties were very appreciably less than those of the nickel-free chromium-molybdenum steels. The author agreed that a considerable amount of useful data on steels at elevated temperatures had been accumulated, but considered that published evidence, his own evidence, and apparently that of other contributors to the discussion, indicated that nickel-chromium-molybdenum steels were not the best for the purpose, and they were more subject to the effects of heat-treatment differences than the straight chromium-molybdenum steel. Dr. Hatfield appeared to suggest that were steels for such purposes to be manufactured in the electric furnace, the phenomenon of embrittlement would not be encountered to such an extent. The author would state in reply, that of the 27 steels included in the investigation, 18 were made in the electric furnace; of these 18 steels, 12 showed pronounced embrittlement, and it was safe to infer that if a steel was of the type subject to the phenomenon, manufacture in the electric furnace might minimise or delay embrittlement, but would not eradicate it.

In Table A on p. 374 P were listed the composition and percentage fall in impact value after 844 hr. of 7 steels which were made in the high-frequency furnace; if Dr. Hatfield would refer to that Table he should become convinced that composition played a great part, even when the steels were made by the same process.

In reply to Mr. Turner, the author agreed that caustic embrittlement, temper-brittleness, season cracking, and interpenetration of

TABLE A.—*Composition and Decrease of Impact Value on Heating of Seven Steels made in the High-Frequency Furnace.*

Mark.	Composition			Fall in Impact Value after 844 Hr. %
	Ni. %	Cr. %	Mo %	
D	0·04	0·64	0·40	10
B1	0·96	0·97	0·81	20
R	2·76	1·05	0·98	90
S	4·19	1·02	0·93	95
T	5·31	0·55	1·54	86
U	5·27	0·42	1·09	79
V	5·27	0·56	1·65	79

molten metals affected the life of a material in service, but he would point out that he was not dealing with any of these factors, but was merely considering the effect of stress and temperature in a normal atmosphere in an effort to assist users of steel in their choice where such conditions were to be considered. Probably Mr. Turner's contribution might cause more alarm than the author's paper, because, although he stated that all the steels were embrittled (actually steel *E* was not embrittled), yet he failed to point out in his remarks that in many cases a small amount of embrittlement took place in the early stages of the test, and that very little subsequent embrittlement occurred. It should be appreciated that the paper indicated certain types of steels which would prove superior, from the point of view of embrittlement, to those that had been used in the past, and that the heat treatment of a steel partly controlled the resistance to embrittlement.

The author was pleased to note that the evidence of Dr. Swinden and Mr. Jones confirmed his own, and that they were convinced that the chromium-molybdenum types of steel were superior to the nickel-chromium-molybdenum steels, not only from the point of view of embrittlement at elevated temperatures, but also from that of their creep-resisting properties. Mr. Jones's suggestion that correlation of the effects of various rates of cooling from the tempering temperature and the embrittlement after long times of exposure at elevated temperatures might ultimately lead to evidence which would make it possible to obtain embrittlement data in a shorter period of time, was certainly worthy of serious consideration. He noted also Mr. Jones's remarks regarding the necessity of water-quenching to give the 65–75 tons per sq. in. tensile strength now called for for stud and bolt applications. The author considered that this specification might be appreciably reduced with considerable advantage to the user and no detriment to the steel for such applications.

In reply to Dr. Becker, the author agreed that the paper was not

very helpful in determining the mechanism of failure by embrittlement, nor was he able to carry out any tests in which the dimensions of the notch or speed of the blow was varied. Unfortunately the type of research suggested by Dr. Becker was normally outside the scope of a steelworks research organisation, and was more suitable to that of the academic institutions or the National Physical Laboratory. He would also like to remind Dr. Becker that when reading the paper he emphasised the fact that the deductions drawn were applicable only in such cases where embrittlement was a factor to be considered, and instanced such threaded portions as stud bolts in superheater assemblies. Where such stress concentrators as screw threads had not to be considered, then a notched specimen might not be the best means of determining the usefulness of a material at elevated temperatures.

With reference to his remarks on the effect of a high-temperature tempering treatment, the author would repeat that a considerable amount of evidence was included in the paper which showed that a high tempering temperature was an advantage, provided that it did not encroach into the critical range.

A SURVEY OF THE IRON-CARBON DIAGRAM NEAR ZERO CARBON (BELOW 1000° C.).*

By J. H. WHITELEY, F.I.C. (Consett).

Summary.

Details of a cupric etching method which makes cementite readily apparent in steels containing less than 0·03% of carbon are first given. By means of it the gradual solution of cementite in α-iron on heating above 550° C. is examined. Then, the formation of martensite at still higher temperatures in such non-pearlitic steels is investigated and is shown to be due to the presence of carbon; the presence of nitrogen is not necessary. From a microscopic examination of these two effects the true positions of the lines of the equilibrium diagram in the region under consideration are inferred.

That portion of the iron-carbide diagram relating to a carbon content of less than 0·10% is now frequently published in the form indicated by the unbroken lines *ABCP* of Fig. 1. Point *A*, which indicates the solubility of carbon in α-iron at room temperature, was fixed by Yensen [1] at 0·008%, and this figure appears generally to be accepted as about correct. Point *B* represents the solubility at Ar_1. It is here placed at 0·03%, as was first deduced by Scott [2] from cooling curve results and subsequently confirmed in other ways by several workers, including Yensen,[1] Yamada,[3] and Tamura.[4] But, as pointed out by Andrew and Elliss,[5] the positions of these two points may be affected to some extent by the presence of other substances in solid solution, such as FeO, so that their exact determination for the perfectly pure iron-carbon system has yet to be made and may prove very difficult. Point *B* is joined to the Ar_3 point *C* which has so far been observed in the purest iron available. If Yensen's view [6] that absolutely pure iron will not transform to γ-iron is ultimately found to be correct, a slight shift here from the zero ordinate for carbon would strictly be required. These three points having been fixed by means of the above data, an attempt is made in the present paper to delineate the curvatures of the lines joining them. It is shown that their positions and slopes may be ascertained microscopically with fair precision, when samples of high purity and with carbon contents accurately estimated to the third place of decimals become available.

While several steels containing less than 0·03% of carbon have been used during the investigation, the main part of the work has been done with specimens from a piece of Armco iron plate, $\frac{3}{8}$ in.

* Received January 6, 1936.

thick, in the as-rolled condition. The material had the following analysis :

	%		%
Combined carbon	0·025	Phosphorus	0·005
Silicon	Trace	Manganese	0·03
Sulphur	0·033	Nitrogen	0·004

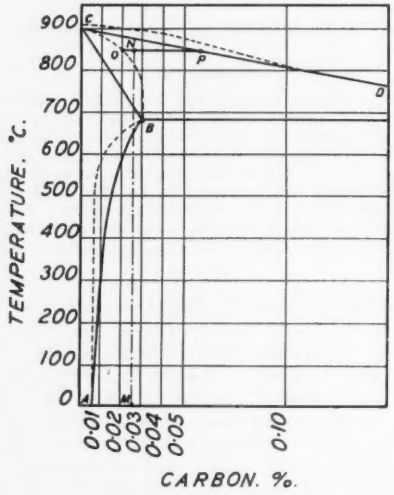

FIG. 1.

A typical illustration of its ferritic structure is given in Fig. 16 (Plate XXXIII.). The ferrite was not entirely homogeneous, however, since a distinctly banded structure in the direction of rolling was evident, especially when the steel was etched with cupric reagents. For each experiment a full section across the plate was taken. In all heat treatments the specimen was attached to a thin nichrome wire holder and inserted in a horizontal tubular electric resistance furnace against a thermocouple placed near the centre; when ready for quenching it was withdrawn and immediately plunged into cold water.

Three etching reagents have been employed, *viz :*

(1) A saturated solution of picric acid in 98% alcohol containing 0·05–0·07 g. of copper chloride per 100 c.c.

(2) A 5% solution of nitric acid in alcohol.

(3) Le Chatelier and Dupuy's cupric reagent[7] containing: Alcohol (95%) 100 c.c., water 10 c.c., copper chloride 1 g., picric acid 0·5 g., hydrochloric acid 1–3 c.c.

The addition of a little copper to the first was found to be distinctly advantageous in differentiating between the weaker γ-iron areas and ferrite in the quenched specimens. Reagent No. 3 was valuable for detecting both cementite and the martensitic constituent, since it produces strong contrasts between these phases and ferrite. The structures it revealed were proved to be identical with those developed by the other two reagents. As, however, this mode of etching was recently criticised by Dr. Hatfield,[8] a detailed description of the author's method of procedure when using it seems desirable. The surface of the specimen is carefully polished in the usual way, and then, without delay, immersed repeatedly in a few drops of the reagent placed just previously in a watch glass. As soon as a brown film of copper has been deposited, the piece is washed either in cold water or in a jet of hot water, when it will dry itself. If the former is used, the surface is blotted on a piece of soft filter paper, care being taken to avoid any rubbing, since this either scratches or removes the film and so spoils the effect. With small specimens of ordinary steels, the time required for etching is usually between five and ten seconds, but larger pieces may take a little longer. The reagent is applied shortly after preparation, because if any length of time is allowed to elapse a lighter-coloured deposit and much weaker contrasts are obtained, probably owing to interference by the invisible oxide film, the formation of which has been demonstrated by Dr. Evans.[13] For further examination the copper film can be readily removed by cloth polishing and the cleaned surface then etched with other reagents.

When specimens of the Armco iron were treated with the cupric reagent a white constituent was invariably to be seen at the grain boundaries, as shown in Fig. 2 (Plate XXXII.). This feature was unexpected, for in previous examinations which had been made the presence of the constituent had not been noticed in this particular sample, the specimens having been well etched with either picric or nitric acid. The steel then seemed to have the entirely ferritic structure seen in Fig. 16, but it was subsequently found that the broken films could be distinctly traced, after using nitric acid, by very lightly repolishing the etched surface on the wet cloth. There could be little doubt that the constituent was cementite, a conclusion which was confirmed by means of sodium picrate. Part of the area shown in Fig. 2 is again seen in Fig. 3 as it appeared after the piece had been cleaned and immersed for 10 min. in the boiling solution. The boundary films have obviously been stained dark by the reagent in a manner characteristic of cementite.

It was thus clear that the cupric reagent was a convenient medium to use for detecting minute cementite crystals in iron very low in carbon, and that, consequently, it afforded a method by which the solubility of carbide in α-iron, as the Ac_1 point was approached, could be gauged with some degree of accuracy. Specimens of the Armco iron were, therefore, heated to different temperatures,

quenched in water and examined. Up to 550° C. no reduction in the quantity of cementite was noticeable even after heating for 1 hr. Fig. 4 illustrates the amount still present at that temperature. A comparison with Fig. 2 will make it apparent that the quantity had not been appreciably lessened. Above 550° C., however, the cementite crystals began to diminish gradually in size and number until at 680° C. no trace of them remained. The cementite-free structure obtained at this temperature is seen in Fig. 7. Two intermediate stages of the process, at 600° C. and 640° C., are given in Figs. 5 and 6 respectively. It was repeatedly found that saturation of the ferrite with carbon was reached with remarkable rapidity. Three minutes' heating, which included the time—about 2 min.—required to bring the specimen to the temperature, was, as far as could be judged, sufficient in all cases to lessen the amount of visible carbide to the same extent as heating for 1 hr. Similar evidence of the speed at which cementite diffuses in the α-iron grains was advanced by the author[9] some years ago. As will be seen later, this rapid diffusion is of importance in explaining the structures which occurred in specimens quenched from higher temperatures.

The above observations led to the conclusion that the curve for the solubility of carbon in α-iron should be represented by the broken line *AB* of Fig. 1. This is in agreement with the author's previous work on the subject[9] and also with the deductions of both Yamada[3] and Köster.[10] The former found that cementite was deposited along the grain boundaries in steels which did not contain sufficient carbon to produce pearlite. Köster determined the solubility curve up to the Ac_1 point from variations in physical properties and by making use of the Eggertz colour test for carbon. As the carbide dissolved in the ferrite the intensity of the colour given by the quenched specimens diminished. From the results obtained he plotted a curve exactly corresponding to that suggested here, except that the maximum solubility is placed at 0·04% of carbon. Thus both microscopic and chemical methods of enquiry indicate that there is no appreciable increase in the solubility of carbide in α-iron below about 550° C., which means that the line must be drawn vertically to that temperature.

At this stage of the investigation the question was considered as to whether the manner in which the carbide was deposited could be altered by suitable heat treatment. Since at 650° C. a few particles still remained undissolved it was to be expected that, given slow cooling, the dissolved carbide would precipitate on these, rather than form fresh nuclei. Further, there was a possibility that repeated treatments at 650° C. would cause the larger crystals to grow at the expense of the smaller, so that eventually a smaller number of comparatively widely spaced massive particles might be produced. A specimen was accordingly heated to 650° C. and cooled in 15 min. to 400° C. twelve times. The effect obtained

is illustrated in Fig. 8, from which it is obvious that spheroidisation of the cementite had occurred. As a consequence, the crystals were much more readily discovered after the specimen had been etched with nitric acid, as shown in Fig. 9. The result, however, was rather disappointing, in that the number of particles present was greater than had been anticipated.

As previously stated, no carbide was visible in specimens quenched from about 680° C. On raising the temperature of quenching, this completely ferritic structure persisted until 820° C. was reached, when, after cupric etching, a few scattered white areas were observed, as depicted in Fig. 10 (Plate XXXIII.). As the temperature was raised still further towards 900° C. these areas grew in size and number. They appeared very rapidly, for a stay of 30 sec. at any of the temperatures used sufficed to produce them to the same extent as heating for 1 hr. or more. It should also be noted that the pieces were quickly heated to the maximum temperature from about 700° C., where they were first held for a short while. Since similar tests in which specimens were slowly heated above 700° C. gave identical results, it was evident that the formation of this new constituent was not dependent upon the rate of heating.

According to the equilibrium diagram, Fig. 1, the steel had now passed from the α-region *ABC* into the $(\alpha + \gamma)$ zone *BCD*. Consequently, two phases should be expected in the quenched specimens, one consisting of a solid solution of carbon in α-iron and the other of martensite. Thus, if the line *MN* is taken as representing the composition of the Armco iron, then, at 850° C., the proportion of γ-iron to α-iron present should be equal to the ratio of the length of the line *ON* to that of *NP*. The carbon content of the α-iron is, of course, then indicated by the point *O*, and that of the γ-iron by the point *P*. From a consideration of the iron-carbon diagram, therefore, it is to be inferred that martensite should appear at some point above 700° C., even in steels containing insufficient carbon to give pearlite, and that, as the temperature is raised, the α-iron should progressively diminish in amount until it eventually vanishes at Ac_3.

This inference was fully confirmed in the present tests. The structure obtained at 850° C. is shown in Fig. 11, where the increased quantity of white areas as compared with that given at 820° C., Fig. 10, will be noticed. When specimens were repolished and etched with nitric acid, these white areas were found to be definitely martensitic in character. A typical example is given in Fig. 15. Between 860° C. and 870° C., however, the action of the cupric reagent on the γ-iron areas, or, better, on the areas due to the formation of γ-iron, was reversed; they continued to expand in volume but now etched darker than the surrounding ferrite, and the most drastic quenching failed to make them appear white as heretofore. Quenching from 880° C. gave the result seen in Fig. 12. The same area when etched with nitric acid is shown in Fig. 13, and a comparison in detail of the two illustrations will make it clear that identical

structural effects are revealed. Most likely this change in tint from light to dark under cupric etching was due, in part, to the diminishing concentration of carbon in the austenite, for it occurred at a point where the areas began to develop quickly as the temperature was raised. Between 830° C. and 860° C. their volume growth was comparatively small; it became very marked above 870° C. Fig. 14 illustrates the proportions of the two phases obtained at 890° C., the lighter constituent again being the α-iron.

An area seen in the top left-hand corner of Figs. 12 and 13 is again shown in Fig. 18 (Plate XXXIV.) under higher magnification. The marginal band is typical and appears to be ferrite, while the centre is minutely striated and rather resembles pearlite. Another example of the same effect is seen in Fig. 24. This tendency of the diluted austenite to decompose was noticed throughout the investigation, and may in some degree be accounted for by the absence of manganese, which is known to have a stabilising influence. But probably the chief factor was the wide temperature range through which the austenite had to pass in quenching. In pearlitic steels, austenite remains stable down to 690° C., but in the present case it would become unstable at about 820° C., *i.e.*, at the line *BOC* in Fig. 1. The difficulty of retaining it would, no doubt, be further increased by the extremely high rate at which carbon dissolves and diffuses in α-iron above 600° C. It seems very probable that the marginal band, which almost invariably surrounded each γ-iron area, was due to this rapid process, quenching not being sufficient to suppress it completely. The speed at which the austenite in this steel was removed below the line *BOC* was well exemplified in an experiment, repeated several times, in which a small specimen was heated to 860° C., withdrawn, and quenched after it had cooled to about 650° C. in 25 sec. No trace of the γ-iron areas could then be detected, nor could the positions they had occupied be located with certainty.

Having thus investigated the changes which occurred in the Armco iron up to the Ac_3 point and found that the γ-iron phase was formed, as theory demanded, the question as to whether the phase disappeared on cooling at the same temperature as that at which it first appeared on heating was next considered. The fact is well known that there is a difference of at least 20° C. between the Ar_3 and Ac_3 points of the pearlite–austenite transformation, and it was of interest to ascertain whether a pronounced lag effect also obtained in the present case. Two specimens were therefore heated to 950° C. and 880° C. respectively, and cooled in the furnace to 820° C., while another was gradually raised to that temperature. All three were then held there for a few minutes, after which they were quenched and examined. A few small areas of martensite were found in each and, as far as could be judged, the quantities were equal. These tests were repeated several times at temperatures between 820° C. and 840° C., with similar results. Except

for alterations in the grain-size the structures produced in cooling from above the Ar_3 point to within the region *BCD* (Fig. 1) were identical with those formed by a direct heating, and vanished at the same temperature. Since there were no indications of any lag it was concluded that the line *BC* for heating occupied the same position as for cooling, or, if not, their separation was very slight.

The changes that took place when the γ-iron areas were tempered followed the usual course, and require little more than passing reference. Specimens which had been quenched from temperatures within the region *BCD* were heated for 30 min. at and above 400° C. and quenched again. At 400° C. the cementite in the areas was not clearly visible under high magnification except at the margins adjacent to the surrounding band (*see* Fig. 18) where it had begun to collect as extremely fine particles. This process became still more evident at 500° C. and, in addition, some carbide could be detected within, as shown in Fig. 19. It will be noticed that the marginal band is free from carbide. At 550° C. the effect was much the same, but at 630° C. the amount of carbide to be seen was distinctly less. At 680° C. it had vanished completely. These tempered structures were revealed equally well by either acid or cupric etching; with the latter, the minute carbide particles remained white against the darkened ferrite matrix. It was repeatedly found that, even in cases where the carbide had dissolved, the areas which had been occupied by the austenite were still differentiated by all the reagents. With the cupric reagent they appeared darker than the surrounding ferrite, and with the picric or nitric acid deeper. They persisted after long heating at 700° C., but gradually weakened at higher temperatures.

In order to confirm the deductions drawn from the foregoing experiments relative to that portion of the equilibrium diagram under consideration, tests of a similar kind were next made on other suitable materials. The Armco sample, which had hitherto been used, contained 0·004% of nitrogen, and according to Fry [11] the iron-carbon and iron-nitrogen diagrams are very much alike. Since, however, nitrogen is stated to be more than ten times as soluble in α-iron as carbon, it seemed improbable that so small a quantity as 0·004% would seriously interfere. Nevertheless, for checking purposes, it was desirable to use iron which was as free as possible from this element, and, for that reason, the three samples described below were selected.

(*a*) *Extremely Pure Iron* kindly supplied to the author by Dr. C. H. Desch, F.R.S. No γ-iron areas could be detected in a specimen quenched from 895° C., *i.e.*, just below Ac_3. The structure consisted entirely of ferrite grains, and exactly resembled that of the original material. A thin section weighing about 0·2 g. was slightly carburised by heating it at 950° C. with pure charcoal in a closed silica tube of 15 c.c. capacity. Then, to obtain a uniform distribution of the absorbed carbon, the piece was heated in air in the closed

tube for 3 hr. at 1000° C. On examination, a few small areas of pearlite were seen to be present, and, to eliminate them, the above mildly decarburising treatment was repeated. This time the piece was found to be free from pearlite. The introduced carbide existed as broken grain boundary films similar to, but rather more in quantity than, those shown in Fig. 23. A series of short heatings at progressively higher temperatures was next given, the specimen being quenched and prepared on the same face after each heating. At 550° C. the amount of cementite was apparently undiminished, but at 630° C. it was noticeably less. At 670° C. it had disappeared, and the specimen then had the completely ferritic structure illustrated in Fig. 20. This structure was also produced at 800° C., but at 830° C. some areas of martensite had formed, two of which are shown in Fig. 21. It will be observed that they were bordered by the characteristic ferrite band. At 860° C. these areas had grown considerably in size and number, as represented in Fig. 22; when etched with nitric acid they were very similar to those of Fig. 21. Finally, as a precaution against any possible unequal carbon content, the specimen was quenched a second time from 800° C., and again no martensite was present. These results thus confirmed very satisfactorily those given by the Armco iron.

(*b*) *Electrolytic Iron Sheet.*—This iron had the following analysis:

	%		%
Combined carbon	Trace	Manganese	Nil
Sulphur	0·006	Nitrogen	Nil
Phosphorus	0·004		

As in the previous case, the material when quenched from just below the Ac_3 point was entirely ferritic. A small strip was likewise carburised to about 0·10% of carbon. It was then soaked in an atmosphere of hydrogen for 2 hr. at 1200° C., in order to reduce the carbon content and distribute it uniformly. On examination, this was found to have been effected, for only a few broken films of cementite were to be seen at the grain boundaries, as shown in Fig. 23. When the piece was heated for 2 min. at 650° C. and quenched, no carbide was visible. The same completely ferritic structure was obtained in a second test at 800° C., but at 860° C. areas of γ-iron appeared. They were white, as usual, when etched with the cupric reagent; with nitric acid they gave the typical structure seen in Fig. 24. These tests were repeated on this specimen twice with similar results. The structures obtained were the same in every respect as those given by sample (*a*). Clear evidence was afforded by both irons, therefore, that carbon alone, when present in an amount insufficient to produce pearlite, can still cause the formation of austenite at some temperature between Ac_1 and Ac_3, for the nitrogen contents of the two samples were negligible. Conversely, it is very probable that iron containing a little nitrogen and no carbon will be found to give comparable effects when quenched from within the same temperature range. In fact, a careful study

FIG. 2.—Fe_3C in Armco Iron. Cupric etch. × 300.

FIG. 3.—Same as Fig. 2. Sodium picrate stain. × 500.

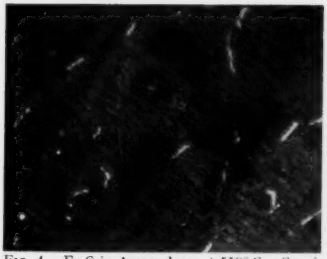

FIG. 4.—Fe_3C in Armco Iron at 550° C. Cupric etch. × 300.

FIG. 5.—Fe_3C in Armco Iron at 600° C. Cupric etch. × 300.

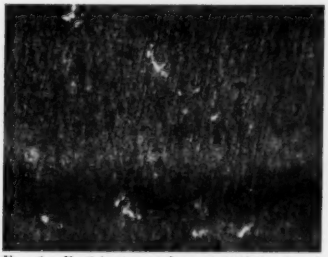

FIG. 6.—Fe_3C in Armco Iron at 640° C. Cupric etch. × 300.

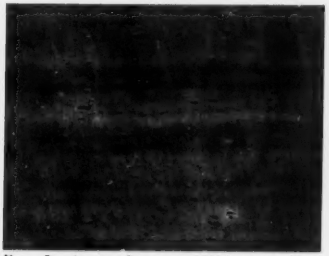

FIG. 7.—Armco Iron at 680° C.; no Fe_3C. Cupric etch. × 100.

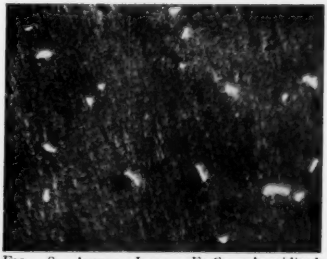

FIG. 8.—Armco Iron; Fe_3C spheroidised. Cupric etch. × 300.

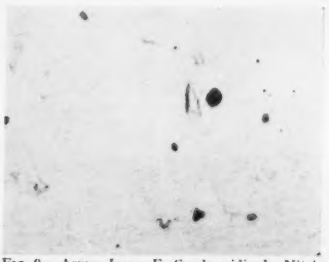

FIG. 9.—Armco Iron; Fe_3C spheroidised. Nitric etch. × 300. [*Whiteley.*

[*To face p.* 384 P.

FIG. 10.—Armco Iron; W.Q. 820° C.; γ-iron white. Cupric etch. × 100.

FIG. 11.—Armco Iron; W.Q. 850° C.; γ-iron white. Cupric etch. × 100.

FIG. 12.—Armco Iron; W.Q. 880° C.; γ-iron dark. Cupric etch. × 100.

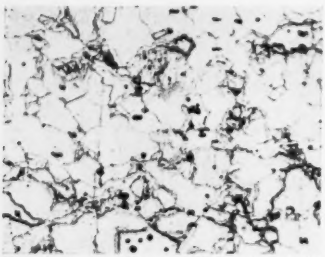

FIG. 13.—Same as Fig. 12. Nitric etch. × 100.

FIG. 14.—Armco Iron; W.Q. 890° C.; α-iron light. Cupric etch. × 100.

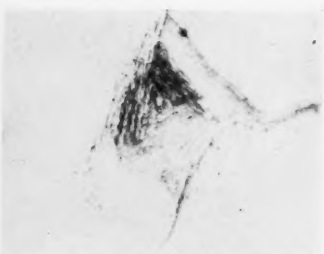

FIG. 15.—Martensite in Armco Iron, W.Q. 850° C. Nitric etch. × 900.

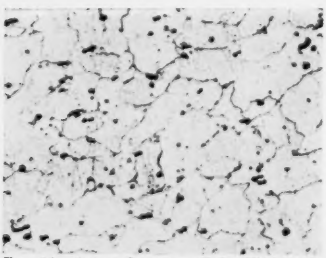

FIG. 16.—Armco Iron as rolled. Nitric etch. × 100.

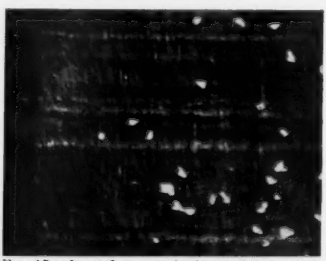

FIG. 17.—Ingot Iron, partly decarburised; W.Q. 850° C.; γ-iron white. Cupric etch. × 40.

[*Whiteley.*

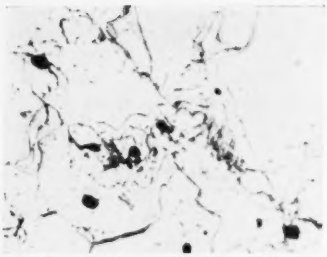

FIG. 18.—Same as Fig. 13. × 300.

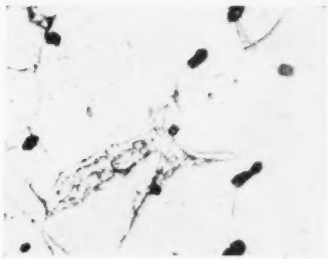

FIG. 19.—Armco Iron; W.Q. 860° C., T. 500° C. Nitric etch. × 500.

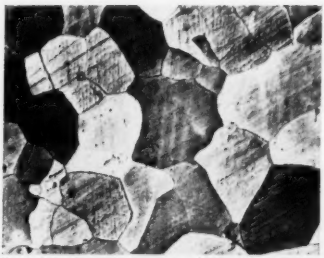

FIG. 20.—Pure Iron, carburised, W.Q. 670° C. Nitric etch. × 100.

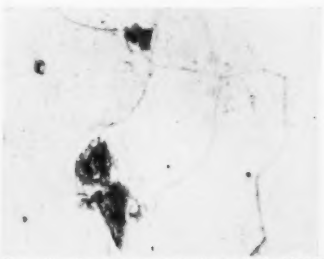

FIG. 21.—Pure Iron, carburised, W.Q. 830° C. Cupric etch. × 300.

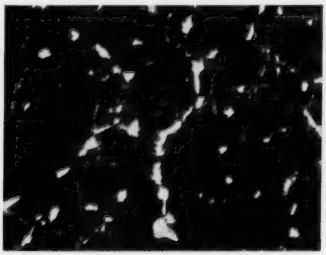

FIG. 22.—Pure Iron, carburised, W.Q. 860° C. Nitric etch. × 100.

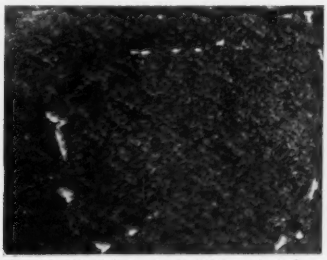

FIG. 23.—Fe_3C in Carburised Electrolytic Iron. Cupric etch. × 300.

FIG. 24.—Carburised Electrolytic Iron, W.Q. 860° C. Nitric etch. × 150.

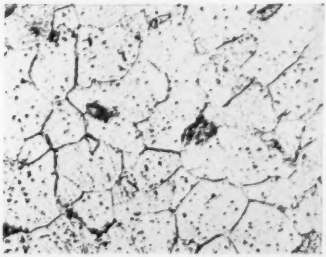

FIG. 25.—Carbonyl Iron, W.Q. 880° C. Nitric etch. × 100. [*Whiteley.*

of this particular field of the system Fe–C–N might prove of much interest.

(*c*) *Carbonyl Iron.*—The carbon content of this sample was 0·015%, but otherwise it was of fairly high purity. An analysis gave :

	%		%
Combined carbon .	0·015	Phosphorus . .	0·005
Silicon . . .	Trace	Manganese . .	0·01
Sulphur . . .	0·003		

A piece was heated to 950° C. and cooled in the furnace, but no carbide could be detected in it with certainty, possibly on account of the minute porosities which seemed to develop when the specimen was etched. In any case, if any free cementite was present, it must have been very finely distributed. No structural change occurred up to 850° C., but when the piece was quenched from 880° C. a few sharply defined γ-iron areas appeared, as shown in Fig. 25; in character they were like those observed in the other similarly quenched samples. The relatively small number of areas formed, as compared with the many produced in Armco iron at the same temperature, was no doubt due to the lower carbon content, an inference quite in accordance with the explanation of their origin which has been advanced. Thus, from a consideration of the changes which should occur to comply with the equilibrium conditions represented by the iron-carbon diagram, the effects obtained throughout the investigation could be satisfactorily accounted for. While much further work may be necessary to determine very exactly the positions of the curves dealt with, it is nevertheless submitted that the facts here given justify the conclusion that their directions are shown by the broken lines in Fig. 1. In particular, the evidence indicates that the line *CD* must be nearly horizontal at the outset, for only by so placing it can the volume of α-iron areas seen in Figs. 14 and 25 be accommodated.

In conclusion, two points bearing on this investigation remain to be dealt with :

(1) Some excellent illustrations of the γ-iron constituent here described were published in 1917 by Brooke and Hunting.[12] They had discovered the structure in quenched pieces of Armco iron and concluded that this material " possesses the property of throwing out of solution, between the Ar_3 and Ar_2 points, a eutectoid, &c." They further stated that " the temperatures at which the occurrence and disappearance of the eutectoid occur coincided so remarkably with the beginning and end of the brittle zone, as observed in practice, that it was judged that herein lay the cause of the pronounced red-shortness." It can now be confidently asserted that no such eutectoid exists. As previously explained, the simulated eutectoid appearance at times exhibited by the γ-iron areas is no doubt mainly the result of their partial decomposition in the early stages of quenching, when they pass through the temperature

range in which they are highly unstable. Further, it is clear that this so-called eutectoid formation has no connection with the peculiar red-shortness of Armco iron, since the same structures can be produced in other materials, such as carburised electrolytic iron, which are not characterised by this property.

(2) It has been demonstrated that steels containing insufficient carbon to give rise to any pearlite can still yield areas of pronounced martensite when quenched. A method is thereby suggested by which the distribution of the carbon in such steels may be conveniently observed. It consists in quenching the samples from a temperature within the area *BCD* of Fig. 1, preferably about 850° C., so that the martensitic areas will appear white with cupric etching. As an illustration, the effect so obtained on a partly decarburised specimen of the Armco iron may be given. The section had been allowed to scale in air at 960° C. for 2 hr. When cut in two and examined internally no cementite was visible close to the edges, but at a short distance away it began to appear and to increase in quantity, until within about $\frac{1}{20}$ in. from the edge the normal amount was judged to be present. A removal of the carbon at and near the surfaces had, therefore, taken place by oxidation. The same piece was then heated at 850° C. for 2 min. and quenched. When etched with the cupric reagent the diminishing carbon content towards the edges was very clearly revealed, as shown in Fig. 17. The test thus appears to be reliable. Probably the need for a method of this kind is limited, but it may prove of use, for example, in exploring the distribution of carbon in the relatively pure skin of dead soft rimming steels.

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DISCUSSION.

Dr. C. H. DESCH, F.R.S. (Vice-President, Teddington), said the paper was exceedingly useful in determining the real solubility line of carbon in α-iron, and he thought that the new line which was proposed was probably much nearer the truth than that which had usually been drawn. It was natural, of course, to draw the line with a fairly even slope, as in the case of the full line in Fig. 1 of the paper, and the dotted line which had been drawn by the author looked a little strange; but as a matter of fact in most of the age-hardening non-ferrous systems which were being studied at present the dotted line was the kind of curve which was usually found—very little change in solubility until a certain temperature was reached, and after that a fairly rapid change. There was nothing improbable about that.

The technique which had been used for detecting and observing the small quantities of carbide would be extremely useful. It had always been very troublesome to make sure when carbide was present, if the quantity was very small. The ordinary methods of etching did not succeed.

The author had always been able to carry out interesting experiments with very small quantities of material. For example, the National Physical Laboratory were able to let him have only quite a small piece of their highly purified iron, but he carried out a number of experiments on it, and in the case of the crucial experiment described in the paper he used 0·2 g. of iron.

On the first page of the paper there was a reference to Yensen's view that absolutely pure iron might not show any allotropic change. Perhaps the fact had been overlooked that Yensen had now withdrawn that suggestion. The purest iron examined by the author showed the allotropic change just as strongly as that which was slightly impure.

With regard to the carbonyl iron, the analysis showed a certain amount of carbon present, but it should not be forgotten that there was a quantity of oxygen present about equivalent to the carbon, and so when that was heated to any high temperature, say 950° C., the carbon and oxygen largely went off together as carbon monoxide, and after heating the carbon content was very considerably reduced. That made a little difference in the interpretation of the results with carbonyl iron. It was a material which gave a very pure iron, provided that it was treated in such a way as to eliminate carbon and oxygen together.

At the time when Brooke and Hunting's paper was produced, the speaker had been very much interested in the structures which it showed, and had made the suggestion that their particular structure was due to nitrogen, because when their experiments were repeated the eutectoid had neither the appearance nor the colour of pearlite, but resembled the nitride eutectoid, and when repeating

a number of the experiments and introducing nitrogen he (the speaker) obtained that kind of structure. That was his reason for supposing that nitrogen played an important part in producing the structure. He would like to know whether the structures found by the present author in the pure iron which was known to be free from nitrogen agreed with Brooke and Hunting's, not only in the general appearance, as shown in the photographs, but also in the characteristic yellowish colour.

What one would like to know next was how far the solubility of carbon was affected by the presence of other elements. It certainly would not be the same in iron containing small quantities of other elements in solid solution, and that, of course, meant a rather extended series of experiments.

Dr. W. H. HATFIELD, F.R.S. (Vice-President, Sheffield), congratulated the author on a very interesting piece of work. As Dr. Desch had said, the author had a peculiar facility for carrying out experimental work of the kind in question, and it was very valuable that he should have devoted so much time to the particular question dealt with in the paper. Personally, however, when he read the paper he came to a general conclusion which really did not support the conclusion that Dr. Desch had drawn. The experimental work was very nicely carried out, but it had its limitations; it was very qualitative, and, whilst the deductions drawn were very interesting and had all the value which qualitative work could have, yet it must not be considered that in any sense the author had solved the problem with which he had set out to deal.

To begin with, the author's experiments had been conducted on Armco iron, a most unsatisfactory material on which to perform such work, as Dr. Desch would be the first to agree. The Ingot Committee had been to a great deal of trouble thoroughly to examine and to make available the real facts concerning such material, and a content of the nature of 0·2% of oxygen in his opinion invalidated the material as one for scientific research. He was very sorry that resources and experimental facilities had not permitted the subject to be tackled in the only way which would give a quantitative basis for the modified line which the author suggested, namely, that this work should have been done on pure iron such as Dr. Desch was able to supply, and that compositions should be based on that material, with sufficient sensitivity as regards carbon content, so that the investigations should have a more satisfactory basis. What he was saying was no criticism of the very delightful investigation which the author had carried out, but he hoped it would make it clear that he for one could not accept such a qualitative investigation as settling the problem under consideration.

It did, however, bring out and emphasise what was very important to members of the Institute, namely, the increased solubility of carbide in α-iron below the carbon change-point.

That was very often overlooked, but, as Dr. Desch had said, that phenomenon was of great importance in regard to the behaviour of many steels as a result of treatment in the low range of temperatures.

On the last page of the paper, at the end of his first conclusion, the author said: "Further, it is clear that this so-called eutectoid formation has no connection with the peculiar red-shortness of Armco iron, since the same structures can be produced in other materials." It might be irrelevant to the subject of the paper, but since the author had himself referred to the matter the speaker would like to ask, if that was not the explanation of the red-shortness, would the author be good enough to give an alternative explanation?

Equilibrium diagrams were generally based on cooling curves, and the experimental work in the present case was more analogous to heating curves. If one quenched specimens from ascending temperatures one obtained data more comparable with a heating curve than a cooling curve, and that must be taken into consideration in its bearing on the exact position of the lines in question. It must also be emphasised that even in the case of the small specimens used the preservation at the ordinary temperature of the balance of constituents existing at the high temperatures was almost impracticable from a purely experimental point of view.

He had concentrated on pointing out what he regarded as the irremoveable disabilities of the author's line of attack, but he would like to congratulate him on a very interesting paper produced as a result of the procedure adopted.

Dr. E. W. Fell (Manchester) said that Mr. Whiteley's paper was of interest to him in connection with some work he was doing on the plastic distortion of soft steel.

The author's illustrations rather suggested to him that the individual ferrite crystals were not completely surrounded by a continuous film of cementite, because isolated masses of cementite occurred at the crystal boundaries, judging, for example, from Figs. 2 and 3. He would like to ask the author if any of his own work had suggested to him that the individual ferrite crystals in Armco iron and soft steel might be completely surrounded by continuous films of cementite, or even by films of cementite of ultramicroscopical thickness.

Now, a theory, which had received publicity from Körber,[1] and Kuntze and Sachs,[2] had been put forward by Nádai [3] and again by Kuroda.[4] The theory assumed that a network of cementite

[1] "Das Problem der Streckgrenze." *Congrès International pour l'Essai des Matériaux, Amsterdam*, 1927, vol. 1, p. 51.

[2] *Zeitschrift des Vereines deutscher Ingenieure*, 1928, vol. 72, p. 1014.

[3] "Der bildsame Zustand der Werkstoffe," p. 63. Berlin, 1927: J. Springer. *Journal of the Iron and Steel Institute*, 1935, No. II., p. 94.

[4] *Proceedings of the Fourth International Congress for Applied Mechanics*, 1934, p. 207.

existed at the crystal boundaries, and that it was the cause of the well-known yield in soft steel. Under increasing stress, the network was assumed to bear all the load up to the yield point; the network then broke, thus releasing the load on to the ductile ferrite crystals, which extended immediately as a result.

In order to test this theory, the speaker quenched a small tensile test bar of Armco iron from 750° C., and another test bar from 700° C., in cold water. Such a treatment should result, according to Fig. 1 of the author's paper, in the removal of any boundary layers of cementite. More test bars of soft steel were heated in hydrogen so as to decarburise them. In all of these, on subsequent loading in tension, the Piobert effect (known also as Lüders' lines and "stretcher strains") was well marked on the polished surface of the test bars, and from that it might be concluded, with justification, he thought, that the bars would possess a well-marked yield.

Moreover, the presence of networks of such brittle intercrystalline substance as cementite, might be expected to make soft steel unworkable in the cold state—in a similar way, for example, to the effect of small amounts of bismuth in forming brittle intercrystalline films, and thus making gold unmalleable.[1]

Further facts might be mentioned in support of what he had just said, but, in conclusion, it seemed to him most improbable that the yielding of iron and soft steel was due to the presence of a cementite network.

Dr. M. L. Becker (Teddington) said that his remarks had been partly covered by Dr. Hatfield's contribution. The author had expressed a great liking for the cupric reagent, but personally he could not say that his own experience would justify that. He felt that the cupric reagent certainly etched steel and showed up the grain boundaries, but he was not at all convinced even now that the actual white spots revealed by the cupric reagent really did constitute cementite, as the author suggested. It was true that they showed up in the same position when the author etched with sodium picrate, but he thought the photographs in the paper supported the view that the areas covered by the white spots when the cupric reagent was used for etching were very much larger than the black spots or black lines revealed by the sodium picrate. He felt that the white spots actually showed the presence of oxide. No mention seemed to be made in the paper of the possible presence of oxide, but the author might say that he took pure iron, which of course contained only a very small quantity of oxygen, from the National Physical Laboratory, and simply added carbon to it; but he (the speaker) would like to point out that during the carburisation with carbonaceous material a certain amount of oxidation was quite possible and must in fact have occurred. He did not wish

[1] Arnold, *Fourth Report to the Alloys Research Committee*, 1897, p. 80.

to infer that there was any solid oxide present, but at the same time as the carbon was entering into solid solution in the iron during carburisation he believed that oxygen was also going into solid solution, and therefore he was not at all surprised to find that the same type of result was obtained on the very pure iron as was obtained on the Armco iron samples.

CORRESPONDENCE.

Professor W. R. D. Jones (Cardiff) wrote that the manufacture of sheets from low-carbon steels or ingot irons had given rise to certain difficulties, one of the chief of which was that although the sheets might have possessed a low hardness value and high ductility immediately after heat treatment, it had been found that in certain cases after a few weeks' storage the sheets had become harder and less ductile. This occurrence might be troublesome in sheets manufactured in Great Britain and subject to lengthy transport, since on arrival they might not be up to the specification which had been obtained before shipment.

This loss of ductility was evidence of an ageing phenomenon—a process accompanied by precipitation in which there was a movement towards equilibrium both constitutional and mechanical and away from any possible unstable condition set up by cooling abruptly from higher temperature ranges.

Experimental evidence was in favour of the view that this type of ageing was most probably due to carbon and not to nitrogen. Although, as stated on p. 383 P, the iron-carbon and the iron-nitrogen diagrams were very much alike (in the range of materials under consideration), there were definite differences which precluded nitrogen from being the cause of this type of ageing (without previous straining). Steels of widely differing nitrogen contents were equally susceptible to ageing, and much higher concentrations of nitrogen than that given in the paper, which was typical of these ingot irons, were necessary in order that supersaturation and reprecipitation might occur.

It was in this connection, therefore, that he welcomed this interesting paper, especially when it could be stated that the increase in hardness, or reduction of ductility, was more pronounced and definite in material containing 0·04% of carbon than was the case with steel containing 0·10–0·15%. From this point of view the value of the experiments would have been increased considerably if some mechanical tests had been carried out.

The oxygen content of Armco iron might amount to 0·15–0·20%, which was fairly evenly distributed both in regard to the inclusions so commonly seen in Armco iron (Fig. 16 of the author's paper) and the high proportion which was held in solid solution. The dissolved oxygen increased the solubility of Fe_3C in ferrite and would

therefore not only alter the positions of the lines in the equilibrium diagram given in Fig. 1 but would also affect the ageing properties. This was quite apart from the effect of oxygen in the mechanical ageing of soft steels after even low degrees of cold-work following heat treatment. This had been discussed by Davenport and Bain,[1] who stated that " Ferrite seemingly supersaturated with oxygen rejects an iron-oxygen compound in the slip bands of cold-worked grains and is thereby hardened."

If carbon solubility were accepted as the cause of this ageing phenomenon then a stabilising treatment was possible, on the basis of Fig. 1, by heating to 100° C., which would precipitate the dissolved carbon with sufficient speed to give an even dispersion and coalescence. If the temperature of pre-ageing were increased to 300–400° C. then on subsequent ageing at 40° C. there was still a definite though small hardening effect. This did not accord with the author's contention that the line *AB* should be vertical from about 500° C.

The author had decided on such an important alteration in a part of the constitutional diagram which had been generally accepted that more details of the experimental work would lead to greater confidence—it would be useful to know the size of the full section across the plate used in the heat treatment experiments. The method of withdrawing the specimen from the tube and then quenching was not as rapid as that of dropping the specimen directly into the quenching tank. As the author himself suggested in paragraph (*c*) " Carbonyl Iron," " much further work may be necessary to determine very exactly the positions of the curves."

Professor E. H. Schulz and Mr. W. Fahrenhorst (Dortmund) wrote that with small carbon contents the author found no hysteresis between Ac_3 and Ar_3. In pure iron, however, the occurrence of hysteresis between these points had been demonstrated. It was doubtful whether the addition of carbon depressed the hysteresis to lower values.

The solubility of carbon in ferrite was given by the author as 0·03% at 680° C., whereas Köster [2] found the value to be 0·043% at 710°. Mr. Whiteley designated the temperature of 680° as the pearlite temperature (A_1 point). According to Oberhoffer,[3] however, Ac_1 lay at 740° regardless of the carbon content, whereas the position of Ar_1 was dependent on it, and, in fact, shifted from 707° for low carbon contents to 721° for 0·9% of carbon. So far as the writers were aware, the temperature of 680° had no significance for iron-carbon alloys. The saturation curve of carbon in ferrite from room temperature up to the pearlite temperature assumed by Mr. Whiteley coincided with that put forward by Köster. In

[1] *Transactions of the American Society for Metals*, 1935, vol. 23, p. 4.
[2] *Archiv für das Eisenhüttenwesen*, 1928–29, vol. 2, p. 503.
[3] " Das technische Eisen," Second Edition. Berlin, 1925 : J. Springer.

Mr. Whiteley's case this gave a solubility of 0·03% of carbon at 680°; on extrapolation to higher temperatures, a solubility of 0·04% of carbon at 710° was also reached. In Fig. A Mr. Whiteley's

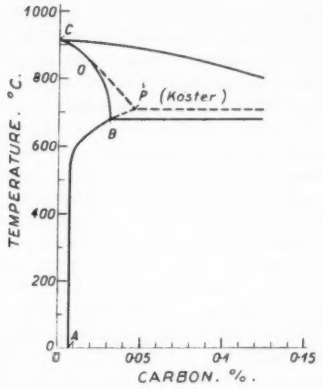

FIG. A.

diagram was reproduced, with the extrapolated curve indicated by a broken line.

According to the writers' own experiments, the etching reagent recommended by Mr. Whiteley appeared to be in no way superior to the ordinary etching with sodium picrate solution.

AUTHOR'S REPLY.

Mr. WHITELEY replied that he agreed with Dr. Desch that it was very troublesome to make sure that free carbide was present in iron when the quantity was minute. From experience gained during the course of the investigation, he felt sure that many of the completely ferritic structures which had been illustrated in the past had really contained undetected cementite. With regard to Yensen's suggestion that perfectly pure iron might not show any allotropic change, he was not aware, when preparing the paper, that this had been withdrawn, nor had he since seen any definite statement to that effect. It was true that in a recent discussion [1] Yensen said "One would, therefore, be inclined to concede the point that pure iron actually goes through allotropic transformations," and perhaps this was the statement to which Dr. Desch referred. Dr. Desch's remarks on carbonyl iron were extremely interesting. He had long felt certain that carbon reacted with

[1] *Transactions of the American Society for Metals*, 1936, vol. 24, Mar., p. 71.

iron oxide in steel at temperatures above 1000° C. with the liberation of carbon monoxide in amounts sufficient in some cases to force the grains apart. At the same time it did not seem likely, in the short heatings given to the carbonyl iron below 900° C., that there was any serious loss of carbon, since no appreciable loss occurred in Armco iron after much longer heating except at the edges (Fig. 17). There was, however, room for an extensive enquiry on the subject. He was afraid he did not quite understand Dr. Desch when he referred to the characteristic yellow structure in connection with the work of Brooke and Hunting. He had not seen this tint in any of the specimens. Possibly because of the absence of manganese, the γ-iron constituent formed in the carburised electrolytic and pure irons was, if anything, more sharply defined than in the Armco iron when etched with the acid reagents, but otherwise the characteristics were in all cases the same.

Replying to Dr. Hatfield, he wished in the first place to thank him for his appreciative remarks. That the work was, in a sense, qualitative he did not deny. At present there seemed to be no other way of dealing satisfactorily with the subject. The lines *AB* and *BC* (Fig. 1) differed from the other lines of the diagram, in that thermal investigation could not be used to determine their positions, as there were no arrest points. Even when a series of pure irons was available, containing uniform and accurately estimated carbon contents ranging from nil to, say, 0·04%, further work in this direction must, therefore, still be subject to the same limitation. Dr. Hatfield objected to the use of Armco iron because of its oxygen content. He (Mr. Whiteley) was, of course, well aware of the presence of that impurity, and consequently was particularly observant as to its possible effects on the structures obtained. As far as he could judge, they were negligible, since the same sequence of results was given by the much purer irons. He would go further, and say that in the absence of carbon and any appreciable amount of nitrogen the effects described would not be obtained, no matter how much or little oxygen might be present. He would also point out that the same objection could be made to the whole of the iron-carbon diagram now in use, for no precautions appeared to have been taken by any individual to ensure that the materials used for its determination were free from oxygen. Hitherto, the effect of this element on the critical points and structures given on quenching had not received much attention, and until definite proof was forthcoming that oxygen was soluble to any extent in solid iron containing carbon, its effects, if any, must remain uncertain. In any case, for practical purposes, it seemed desirable to use Armco iron as one of the samples, since most, if not all, commercial dead soft steels undoubtedly contained oxygen in one form or another; also, a good supply being available, a detailed study of the structures and their mode of formation could be made with it. As regards the peculiar red-shortness of Armco

iron, he regretted to say that he had no explanation to offer, but he had seen it stated that if the sulphur content was reduced to below 0·01%, the red-shortness disappeared. Dr. Hatfield's statement that "the preservation at ordinary temperatures of the balance of the constituents existing at high temperatures was almost impracticable from a purely experimental point of view" also required comment. He presumed that it was the γ-iron constituent which Dr. Hatfield had in mind, for there could surely be no question as to whether carbide could be preserved. It was, of course, true that austenite could not be retained in ordinary soft steels, but he had been careful to point out that the areas where it had existed could readily be detected and that they frequently contained a structure which was martensitic in character. Since the quenching method was known to afford a very satisfactory check on thermal analysis in other regions of the diagram, he failed to see why objection should be made when it was used on dead soft non-pearlitic steels.

In reply to Dr. Fell, he had never seen any hypo-eutectoid steel containing a continuous network of cementite. The natural tendency of cementite films at the grain boundaries was to break up and spheroidise, and, for that reason, he was very sceptical as to the possibility of the presence of carbide films of ultramicroscopic thickness. Dr. Fell's work certainly appeared to negative this supposition.

Dr. Becker was evidently not convinced that the constituent shown in Figs. 2 and 3 was really cementite. He admitted, however, that each particle had the same position and outline in the two illustrations, but considered those in Fig. 2 to be due to oxide; in fact he seemed to be completely obsessed by the oxygen bugbear. To satisfy him, he (Mr. Whiteley) supposed, a third illustration should have been included, showing the unetched surface. He could only now assure him that no visible oxide was present in places where the constituent existed. He would further point out that the Armco iron contained numerous particles of oxide (chiefly FeO), and these invariably appeared dark, without any white border, after cupric etching, as shown, for example, in Figs. 6 and 7. It was true that the thickness of the films in Fig. 3 appeared less with sodium picrate, but he had noticed the same effect to occur when small carbide particles were etched first with sodium picrate and subsequently with nitric or picric acids. With sodium picrate they appeared to be smaller. Also, it might be that with the cupric reagent the edges of the particles were not sharply defined, there being a minute border of ferrite which did not take the copper deposit. If so, the effect was to make the positions of the carbide more prominent and observable. As regards the cupric reagent, he had given the formula as published by Le Chatelier and Dupuy, in which the quantity of hydrochloric acid could vary between 1 and 3 c.c. If Dr. Becker had used the maximum amount, that

might be the reason why the grain boundaries appeared. He (Mr. Whiteley) always used from 1·5 to 2·0 c.c., and also he preferred redistilled commercial methylated spirits to alcohol, as he was of the opinion that it gave more satisfactory results. The reagent was undoubtedly very sensitive and required some practice and experience in its use. With regard to Dr. Becker's concluding remarks, he would refer him to Fig. 17, which showed the intentionally decarburised skin of a piece of Armco iron. If oxygen could pass into solid solution by carburising, as Dr. Becker thought, it could surely do the same in decarburising in air, but, in the above illustration, the γ-iron areas were not present where the carbon had been eliminated, nor was any white constituent shown when the air-cooled piece was etched with the cupric reagent. From various experiments not mentioned in the paper he had no doubt that the cupric reagent could be thoroughly relied on to detect carbide.

Professor Jones raised an interesting point on ageing phenomena. The statement that dissolved oxygen increased the solubility of Fe_3C in ferrite could not, he thought, be accepted at present as definitely proved. Further, his own observations indicated that if more than about 0·01% of carbon was to be retained in α-iron, the steel must be very quickly cooled from between 550° and 700° C., otherwise the excess carbide would be precipitated on existing particles or else appear separately at the grain boundaries. Consequently, he had never been satisfied that the age-hardening to which Professor Jones referred was really due to carbide precipitation. In any case, there might be other causes, so that to use this ageing effect to prove that the line *AB* (Fig. 1) was not practically vertical was scarcely a valid argument. He would mention that the time taken in withdrawing and quenching the small specimens was normally less than two seconds. Also, as stated in the paper, the Armco plate from which the specimens were cut was $\frac{3}{8}$ in. thick.

Professor Schulz and Mr. Fahrenhorst had misunderstood his remarks in saying that he had found no hysteresis between Ac_3 and Ar_3. As a matter of fact, he had made no attempt to determine the exact position of the A_3 point metallographically. He knew of no reagent which would detect with certainty, in very low-carbon steels, the first appearance of ferrite in cooling or the precise point of its disappearance in heating. His observations were entirely confined to the line *BC*, *i.e.*, the temperature at which the γ-iron phase first appeared in heating and disappeared in cooling, which, of course, was not the A_3 point. As far as he could ascertain, the temperatures were the same in the two cases. The statement that "Ac_1 lay at 740° C. regardless of the carbon content" apparently required qualification, since Ac_1 was absent in steels containing less than 0·03% of carbon. As regards the exact position of point *B*, he had accepted the general opinion that it was to be placed at 0·03% of carbon. Very probably its position varied somewhat according to the nature and extent of other

impurities present in the ferrite. The temperature range 707–721° C. for the Ar_1 point seemed to him to be rather high, but it was, of course, entirely a question of accurate pyrometry. From Professor Schulz and Mr. Fahrenhorst's concluding remark, he supposed he might infer that they considered the cupric reagent to be equal to, but no better than, sodium picrate for detecting small amounts of carbide. He was of the opinion, however, that there would be much more difficulty with sodium picrate in presenting a quantitative idea of the amount of carbide remaining in a series of heat-treated samples, such as he had endeavoured to do in Figs. 2 to 7 by means of the cupric reagent.

FURTHER EXPERIMENTS ON THE EFFECT OF SURFACE CONDITIONS ON THE FATIGUE RESISTANCE OF STEELS.*

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Summary.

The investigation has been carried out as a continuation of previous work to determine the factors which cause the low fatigue resistance of unmachined steels, and to develop methods whereby the fatigue resistance can be improved.

Section I. of the paper gives the results of fatigue tests on two typical spring steels carried out to show the importance of surface irregularities of shape, both acting alone and in conjunction with surface decarburisation. Section II. describes experimental attempts to improve the fatigue resistance of heat-treated steels by recarburising the decarburised surfaces produced during the manufacture of the steel. Section III. gives the results of fatigue tests on unmachined steel forgings of over 100 tons per sq. in. tensile strength; Section IV. gives the results of a few fatigue tests on unmachined rolled mild steel.

It is concluded that the combination of surface irregularities or inclusions with surface decarburisation is the major cause of the low fatigue resistance of unmachined spring steel plates. Thus the combination of semi-circular surface grooves $\frac{1}{8}$ mm. in radius together with surface decarburisation lowers the fatigue limit of a high-class silico-manganese steel from $\pm$ 46 tons per sq. in. to $\pm$ 11 tons per sq. in. Surface recarburisation of decarburised steels was found to increase the fatigue limit in some cases, but such treatment can hardly be recommended for general commercial application. The effect of the unmachined surface on very high tensile forgings is very marked, the endurance fatigue limit being less than that of unmachined mild steel; it is concluded that it is most inadvisable for these very high tensile forgings to be subjected to fatigue stresses in service when the surfaces are in the as-forged heat-treated condition. It is also concluded that the effect of the unmachined surface on the fatigue strength of mild steel is not important, although exceptions can occur.

Introduction.

In previous papers experimental evidence has been given of the great importance of surface conditions in affecting the fatigue resistance of heat-treated spring steels; in particular it has been shown that surface decarburisation is one very important factor. It is well known, however, that surface irregularities of shape, such as surface scratches, pits, machining marks, &c., have a marked

* Communication from the National Physical Laboratory received February 17, 1936.

influence on the fatigue resistance of machined steels. In unmachined rolled or forged steels, surface irregularities of shape are present in addition to surface decarburisation, and in the present paper an account is given of experimental work carried out to show the effect of surface irregularities of shape acting alone and also in conjunction with surface decarburisation. It has been shown previously by the authors that heat treatments can be developed whereby surface decarburisation, arising in the heat treatment of machined spring steel plates, can be largely eliminated, but since nearly all as-rolled spring plates are already decarburised at the surface during manufacture, such methods are not directly applicable to the ordinary heat treatment of laminated springs. It would undoubtedly be of advantage if treatments could be devised whereby the fatigue resistance of spring plates could be increased without the necessity for complete machining of the rolled surfaces, and with this object in view, experiments have been carried out to determine whether appreciable improvements could be obtained by light surface carburising treatments; the results obtained are recorded in the paper.

It has also been shown previously that the as-forged and heat-treated surface may have a considerable effect on the fatigue resistance of unmachined forgings of 40–60 tons per sq. in. ultimate tensile strength; this work has now been extended to include tests on forgings of over 100 tons per sq. in. ultimate tensile stress. The results are also given of a few additional tests which illustrate the effect of surface conditions on the fatigue strength of ordinary rolled mild steel.

The whole of the experiments described were carried out at the National Physical Laboratory as part of the research on the effect of surface conditions on the fatigue resistance of steels.

Section I.

Effect of Surface Irregularities of Shape in Conjunction with Surface Decarburisation on the Fatigue Resistance of Spring Steels.

A number of investigators have shown that small surface irregularities of shape such as notches, machining marks, &c., may have a marked effect in reducing the endurance fatigue limit of steel. In general, it is known that the proportionate effect of a given shape of notch in machined steel test-pieces increases with the tensile strength of the steel, and various experimenters have carried out work on this matter with a view to classifying steels in order of notch sensitivity under fatigue stresses. The main object of the present work, however, was not to study the effect of notches in ordinary machined surfaces, but to determine the effect of notches in spring steel surfaces which had been decarburised. Such conditions would approximate to those existing at the surface of a normal unmachined heat-treated spring steel plate in which inclu-

sions and surface irregularities of shape exist in a decarburised surface layer. For comparative purposes, the effect of notches alone, and of surface decarburisation alone, also had to be determined under the selected conditions.

Steels Used.—The steels used for the work were a chromium-vanadium steel, and a silico-manganese steel, both high-quality steels of which the general mechanical properties and appropriate heat treatments were already known.[1, 2] The composition of the steels is given in Table I.

TABLE I.—*Composition of Spring Steels.*

Ref. Mark.	Steel.	C. %	Si. %	Mn. %	S. %	P. %	Ni. %	Cr. %	V. %
*S*5	Chromium-vanadium	0·55	0·29	0·68	Trace	0·01	0·10	1·16	0·27
*S*6	Silico-manganese	0·54	1·95	0·94	0·02	0·02	...	...	...
*S*8	Carbon	0·46	0·09	0·51	0·037	0·026	0·03	...	...
*S*3	Low chromium	0·60	0·26	0·62	0·036	0·036	...	0·56	...

Type of Test and Form of Notch.—The actual tests were rotating beam fatigue tests in normal fatigue testing machines running at 2000–2500 r.p.m.; usually four similar test-pieces 0·200 in. in effective diameter were used for each determination of the endurance fatigue limit, the endurance basis being 10^7 stress reversals. Necessarily, the exact shape of the notch in tests on the notched test-pieces was of considerable importance. Examination of rolled surfaces and sections of spring plates showed that surface irregularities of shape varied from easy contours of large effective radii down to sharp discontinuities containing slag and oxide, such as are shown in Fig. 4 (Plate XXXV.). Accordingly, some arbitrary form of notch had to be adopted, since it was impracticable to study all the forms of surface irregularity which might occur in a spring plate. The form adopted was a semicircular surface groove of $\frac{1}{9}$ mm. radius; the chief factor in deciding on this form was that it could be consistently and accurately produced in a lathe without undue trouble. Two grooves were turned in the test length of each specimen.

Heat Treatment.—As stated above, the test-pieces were heat-treated in accordance with specifications previously published. The chromium-vanadium steel was oil-quenched from 850° C. and tempered at 600° C., whilst the silico-manganese steel was oil-quenched from 950° C. and tempered at 500° C. The test-pieces were rapidly heated in an electric muffle furnace, maintained at the quenching temperature for about 10 min., and quenched in cotton-seed oil. Tempering was carried out in a nitrate salt bath, the time of immersion at the maximum temperature usually amounting to

about 10 min., this being followed by rapid cooling in air. Under these conditions, as discussed in previous papers, a small amount of decarburisation occurred, the effect being sufficient to reduce the fatigue limit from over $\pm$ 40 tons per sq. in. for a machined surface (series *A*, Table II.) to about $\pm$ 30 tons per sq. in. (series *B*).

Where, for the sake of comparison, a soft decarburised layer, extending to a greater depth than the notch, was required, the specimens were given a preliminary decarburising treatment. The method previously used for decarburisation has proved satisfactory, but for the tests under discussion a simplified method, enabling a large number of specimens to be treated at one time, was considered more convenient. A mild steel cylindrical container, closed at one end and provided with a long tube of smaller diameter at the other, was constructed by welding. The container was about half filled with eighteen fatigue test-pieces, the intervening space and remainder of the container being partly filled with strontium carbonate. The container was then heated in a horizontal tube furnace to rather over 1000° C., at which temperature the partial pressure of carbon dioxide developed by the carbonate was calculated to bring about a considerable decarburisation without appreciable oxidation of the iron. After 6 hr. at 1000° C., during which time the container was turned frequently so as to keep changing the position of the specimens and powder, the furnace was cooled and the specimens were removed. In the case of the chromium-vanadium steel almost complete decarburisation was found to have occurred at the surface. At a depth of 0·5 mm. below the surface the carbon content was estimated to be about 0·3%, whilst the total depth of the affected zone was approximately 1·0 mm. The degree of decarburisation and depth affected were rather greater in the case of the silico-manganese steel, and it is therefore certain that for both steels the decarburised zone extended well below the bottom of the grooves subsequently turned on the surface. After the decarburising treatment the specimens were cleaned and then hardened and tempered in the manner outlined above.

Results.—The results of the fatigue tests are given in Table II., and in considering these it must be understood that apart from the surface, as affected by slight or deep decarburisation and by the presence of grooves, the actual body material of all test-pieces of the same steel was in a similar condition throughout. This was checked by hardness tests on the test-pieces after test, the chromium-vanadium steel averaging a diamond pyramid hardness number of about 390 and the silico-manganese steel about 420. The surface hardness of the chromium-vanadium steel specimens after rapid muffle treatment appeared to be about the same as that of the interior, this possibly being due to the failure of the hardness test to detect the presence of a very thin soft layer. The surface hardness of the silico-manganese steel specimens was definitely lower than that of the interior, the depth of material affected being greater in

this instance owing to the higher temperature of treatment. As might be expected, the surface hardness of the decarburised specimens varied a little, but yielded an average diamond pyramid hardness number of about 230 for the chromium-vanadium steel and about 190 for the silico-manganese steel.

The results given in Table II., test series *E* and *F*, provide confirmation of the previous conclusion [2] that surface decarburisation alone is sufficient to reduce the fatigue limit from over $\pm$ 40 tons per sq. in. (test series *A*) to about $\pm$ 20 tons per sq. in., and that the decarburised surface is largely unaffected by subsequent polishing;

TABLE II.—*Summary of Results of Rotating Bending Fatigue Tests (Effect of Notch).*

Test Series.	Treatment and Condition.	Endurance Fatigue Limit. Tons per sq. in.			
		Chromium-Vanadium Steel (*S5*).		Silico-Manganese Steel (*S6*).	
		Neglecting Depth of Notch.	Corrected for Depth of Notch.	Neglecting Depth of Notch.	Corrected for Depth of Notch.
A	Normal heat treatment, completely polished.	$\pm$42 * (1·0)	...	$\pm$46 * (1·0)	...
B	Normal heat treatment, unpolished.	$\pm$31 (0·74)	...	$\pm$24 approx. (0·52)	...
C	Heat-treated, machined and polished, then notched.	$\pm$19·5 (0·46)	$\pm$22·4 (0·53)	$\pm$20·5 (0·45)	$\pm$23·5 (0·51)
D	Machined and notched, then heat-treated.	$\pm$17·2 (0·41)	$\pm$19·8 (0·47)	$\pm$16 approx. (0·35)	$\pm$18·5 approx. (0·40)
E	Decarburised and heat-treated, then lightly polished.	$\pm$20·8 (0·50)	...	$\pm$21 * (0·46)	...
F	Decarburised and heat-treated, unpolished.	$\pm$18 (0·43)	...	$\pm$21 * (0·46)	...
G	Decarburised and heat-treated, then notched.	$\pm$13·5 (0·32)	$\pm$15·5 (0·37)	$\pm$10 approx. (0·22)	$\pm$11·5 approx. (0·25)
H	Decarburised and notched, then heat-treated.	$\pm$15·8 (0·37)	$\pm$18·2 (0·43)	$\pm$10 approx. (0·22)	$\pm$11·5 approx. (0·25)

NOTE.—(1) The results marked * have been previously published; (2) details of the remaining results are given in the Appendix, Section I. (2) The figures in brackets show the ratio of the fatigue limit under the given conditions to the intrinsic fatigue limit, series *A*.

these conclusions apply to both steels. In regard to the effect of notch alone, the particular form adopted reduces the fatigue limit from over $\pm$ 40 tons per sq. in. to about $\pm$ 23 tons per sq. in. (test series *C*); this would be expected from the results of other workers on notch effects. Test series *D* is hardly of major importance in the present connection, but comparison with series *C* shows that the surface action arising from heat treatment of a clean machined notch causes a reduction in the fatigue limit. The results of test series *G* and *H* are of considerable significance; they show that the combination of surface decarburisation with surface irregularity of shape (in this case a given form of notch) produces lower fatigue

results than either the irregularity of shape or the decarburisation alone.

It has already been pointed out that surface irregularities of shape in a spring plate may be much sharper than the notches used in the experiments described above. In order to reproduce the conditions which occur when a very sharp irregularity or small crack is present in the surface of a spring plate, an attempt was made to produce such small irregularities artificially in fatigue test-pieces.

An attempt was made to produce surface quenching cracks by local heating with a small oxy-acetylene flame or electric arc, followed immediately by quenching with a cold water jet, and also by quenching after a short immersion in a hot salt bath. The production of grinding cracks in fully hardened steel by the use of a blunt grinding wheel under heavy pressure, and by frictional heating with a wooden clamp was also tried. It was found difficult to produce cracks by any of these methods in the chromium-vanadium steel, whilst the size and depth of the cracks produced in carbon steel did not appear to be susceptible to any control. These methods were finally abandoned in favour of the following process.*

Fatigue test-pieces were turned from the spring plates to a diameter larger than the required finished size, and a circumferential groove was produced in a lathe, using a saw 0·01 in. thick. The grooves were closed by heating the specimen locally and hammering on the end while hot, a jig being used to hold the specimens so as to prevent bending. They were then heat-treated and finished to size. In this manner, notches were produced with a depth of 0·01–0·02 in. in all the test-pieces.

Two series of tests were made on the chromium-vanadium spring steel. In the first series, *I*, the notches were closed before any heat

TABLE III.—*Results of Fatigue Tests on Specimens of Chromium-Vanadium Steel containing Artificial Surface Cracks.*

Test Series.	Treatment and Conditions.	Endurance Fatigue Limit. Tons per sq. in.	
		Neglecting Depth of Crack.	Corrected for Depth of Crack.
I	Artificial cracks, slightly decarburised at roots.	± 9·5 (0·23)	±12 (0·29)
J	Artificial cracks, definitely decarburised at roots.	±10·3 (0·24)	±12·2 (0·29)

NOTE.—(1) The detailed results of the tests are given in the Appendix, Section I.

(2) The figures in brackets show the ratio of the fatigue limit under given conditions to the intrinsic fatigue limit, series *A* of Table II.

* Previously used by R. E. Petersen, *Proceedings of the American Society for Testing Materials*, 1930, vol. 30, Part I., p. 298.

treatment was performed on the specimens. The notches were slightly decarburised during the heating necessary for closing the saw-cut, and probably also owing to slight penetration of hot furnace gases during the subsequent heat treatment. In the second series, *J*, definite decarburisation was produced at the bottom of the notches by heating the specimens in a muffle furnace at 850° C. with free access of air for $\frac{1}{2}$ hr. and slowly cooling, before closing up the notches and submitting to the normal quenching and tempering.

A decarburised notch produced by this method is shown in cross-section in the photograph, Fig. 5. Table III. gives the results of the subsequent fatigue tests on these test-pieces.

Conclusion, Section I. (*Surface Irregularities and Decarburisation*).

For the two high-quality spring steels investigated in the heat-treated condition, it has been shown that surface decarburisation, and concentration of stress due to a semicircular surface notch $\frac{1}{9}$ mm. in radius, may each alone reduce the fatigue resistance to approximately one-half the intrinsic value for the materials. A combination of the two effects lowers the fatigue resistance to about one-quarter of the intrinsic value in the case of the silico-manganese steel, and to about one-third of the intrinsic value in the case of the chromium-vanadium steel. With an artificially produced surface crack in conjunction with surface decarburisation a still lower fatigue resistance was obtained; in this case the effect of decarburisation is less important perhaps than that of stress concentration.

It is concluded from the foregoing experiments that the combination of surface decarburisation and irregularities of shape is the major cause of the low fatigue resistance of heat-treated unmachined spring steel plates.

The surface decarburisation arises both in the manufacture of the steel plates and in the subsequent heat treatment of the spring; the surface irregularities of shape occur as small pits and marks caused by rolling and as surface scale and oxide penetrations and inclusions. Both decarburisation and surface irregularities appear to be present in nearly all commercial spring steels.

Section II.

Surface Recarburising Experiments.

The effects of decarburisation upon the fatigue resistance of steels having been demonstrated, it was considered advisable to find out whether the carbon could be replaced in the decarburised surface layer, and whether such a case-hardening process could be applied to improve the fatigue resistance of unmachined springs.

Conditions for Recarburising and Nature of Skin Produced.—Experiments were carried out at temperatures from 850° C. to

1000° C. on small samples of silico-manganese steel, chromium-vanadium steel, and Armco iron, using various carburising media such as carbon monoxide, coal gas, graphite powder, charcoal/barium-carbonate, and charcoal/strontium-carbonate mixtures. After treatment for the appropriate length of time, the samples were cooled sufficiently slowly to prevent the formation of martensite, and were then sectioned and examined microscopically. With the possible exception of the coal gas, all the above media depend upon carbon monoxide as the carburising agent, and it is therefore not surprising that all appeared to behave similarly in regard to the carburisation of decarburised surfaces. At temperatures of about 900° C. Armco iron was lightly carburised, but—except in the case of the barium carbonate mixture, which recarburised silico-manganese steel feebly—no appreciable recarburisation could be detected on decarburised surfaces of silico-manganese and chromium-vanadium steel, whilst machined surfaces were actually decarburised to some extent. At 950° C. and above, all the materials were carburised, Armco iron showing a greater depth of penetration than silico-manganese steel, and the latter a greater depth than chromium-vanadium steel. As at the lower temperature, the barium carbonate mixture showed the greatest depth of penetration.

It may be said, therefore, that any of the above media if used at the appropriate temperatures might be used to replace the carbon in decarburised surface layers of steel. The preliminary examination showed, however, that the surface scale, whether it occurred as an even layer or as particles rolled into the metal, was not generally reduced during carburisation or removed on subsequent quenching. In air-cooled samples a very thin layer of ferrite was almost always observed between such scale and the carburised material below, whilst in quenched and tempered samples, hardness tests seemed to suggest that although the original soft decarburised skin had been hardened somewhat, there still remained a very thin layer of softer material on the extreme surface.

A molten cyanide carburising bath, controlled so as to contain about 40% of sodium cyanide, was also used in the recarburising experiments. Tests showed that recarburisation took place rapidly at 950° C., but that the actual surface hardness of quenched specimens was considerably increased by operating the bath at 850° C. and allowing a longer time of immersion. At the lower temperature it is likely that much of the hardening effect is to be attributed to the action of nitrogen, since X-ray analysis indicated the presence of nitrides for some distance below the surface. Apart from the general convenience of salt baths and the rapidity with which specimens can be heated to a uniform temperature without fear of overheating, the cyanide bath possesses what appears to be an added advantage in that a good deal of the scale present on steel is removed during immersion. The extremely thin ferritic band found immediately beneath the scale after carbon monoxide treatments is not

present after cyanide treatment, as is confirmed by the absence of slightly softer material on the extreme surface of hardened and

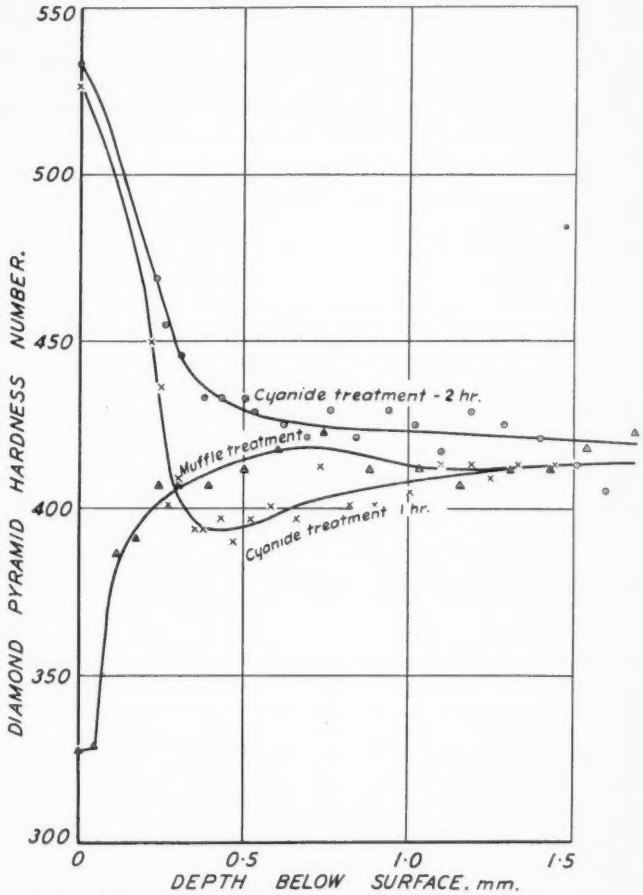


FIG. 1.—Hardness-Depth Curves for Chromium-Vanadium Steel after muffle and cyanide treatments at 850° C. followed by oil-quenching and tempering at 600° C.

tempered specimens. Fig. 1 shows hardness-depth curves for chromium-vanadium steel after cyanide treatment at 850° C. for 1 and 2 hr. followed by oil quenching and tempering at 600° C.

together with a third curve for the same steel in the condition as-rolled and muffle treated. In the succeeding work the 2-hr. immersion period was used as a general rule, although it is certain that for most steels effective rehardening of the soft surface layers could be accomplished in less than half this time. For instance, the decarburised layer on a 0·46% carbon steel (*S*8), amounting in depth to rather over 0·25 mm., was completely recarburised after immersion in the cyanide bath at 850° C. for 1 hr. This is clearly seen in Figs. 6 and 7 (Plate XXXVI.), showing sections of air-cooled specimens before and after treatment.

Preliminary Fatigue Tests using Rotating Cantilever Type Specimens.—Tests were carried out in a rotating cantilever bending fatigue testing machine using specimens machined from $\frac{3}{4}$ in. plate of the form shown in Fig. 2. Owing to the limited size of the testing

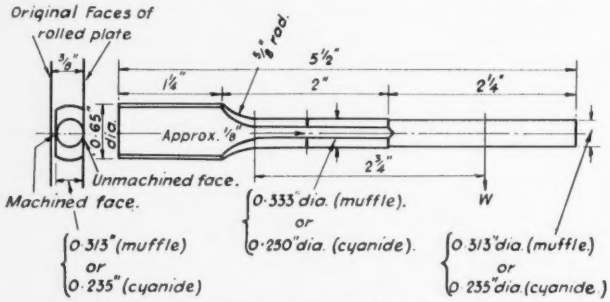


FIG. 2.—Rotating Cantilever Fatigue Specimen used in preliminary tests on the effect of rolled surfaces and recarburisation.

machines available, the full thickness of the plate could not be utilised, so that whilst one of the flats was left in the unpolished condition, representing the original surface of the plate, the opposing flat was fully machined. The lack of symmetry in relation to the thickness of the plate was probably responsible for a certain degree of warping during treatment, but this difficulty was overcome by straightening the specimens and retempering to remove any stresses set up thereby. The results of the tests on silico-manganese steel are given in Table IV., from which the fatigue strength of ordinary heat-treated plates (test series *L*) may be compared with that of recarburised plates (test series *M*) and that of completely machined plates (test series *K*). The quenching temperature of 850° C., used in the case of recarburised specimens, is lower than that generally adopted for the silico-manganese steel, but, as will be seen from the hardness figures, the steel responded satisfactorily to this treatment, and a high surface hardness was ensured. It is of interest to note that in every test-piece broken the fatigue fracture appeared to have been initiated at some point on the flat repre-

senting the rolled surface, which shows that the results obtained applied to the rolled surface, as intended. It must be remembered, however, that the effective plate surface is small in these tests, and since the plates under consideration appear to be unusually free from surface irregularities, it is more than likely that the fatigue range of complete springs would be appreciably less than $\pm$ 25 tons

TABLE IV.—*Effect of Rolled Surface and Cyanide Treatment. Silico-Manganese Steel.*

Rotating specimens with flats.

Test Series.	Treatment.	Hardness Number.		Endurance Fatigue Limit. Tons per sq. in.
		Core.	Skin.	
K	Muffle { O.Q. 950° C. } Both flats T. 500° C. } machined.	...	...	$\pm$45
L	Muffle { O.Q. 950° C. } Not T. 500° C. } machined.	...	...	$\pm$25
M	Cyanide 850° C. 2 hr. { O.Q. 850° C. } Not T. 500° C. } machined.	430	470	$\pm$40

per sq. in. and $\pm$ 40 tons per sq. in. in the case of ordinary commercial treatment and cyanide treatment respectively. On the other hand, as would be expected, the value obtained with both flats machined (test series *K*) agrees well with that obtained when using the normal type of polished round specimen (test series *A*, Table II.). In spite of the limitations of these tests, it appeared that recarburisation might effect an improvement in the fatigue resistance of rolled plate, and the matter was therefore investigated further.

Plane-Bending Fatigue Tests on Flat Plates.—The machine used for these tests was designed at the Laboratory and has been described previously.[3] The form of test specimen used was 18 in. long and $1\frac{1}{2}$ in. wide at the ends; the middle portion was machined down to a width of $\frac{3}{4}$ in. for a length of 6 in. The thickness of the specimen was the same as that of the plate—$\frac{3}{8}$ in.—but this was necessarily reduced somewhat when specimens with machined surfaces were required.

The results of tests carried out on silico-manganese steel and chromium-vanadium steel are given in Table V.

As in the case of the preliminary tests, the first cyanide treatment given to silico-manganese steel was at 850° C. in order to ensure a high surface hardness. Although some doubt was felt, the steel again responded satisfactorily, a fairly uniform core hardness of over 400 being obtained after the usual tempering at 500° C. Unlike the preliminary tests, the results indicate that recarburising the surface of the steel (test series *N*3) only slightly improves the fatigue resistance, the value being considerably below that obtained for

TABLE V.—*Summary of Results of Plane-Bending Fatigue Tests on Silico-Manganese and Chromium-Vanadium Spring Steel.*

Test Series.	Steel.	Treatment.	Diamond Pyramid Hardness Number.		Limiting Safe Range of Stress. Tons per sq. in.
			Interior.	Surface.	
*N*1	Silico-manganese spring steel, *S*6.	Muffle: O.Q. 950° C., T. 500° C. — Machined and polished.	Brinell Hardness 430		0–55
*N*2		Muffle: O.Q. 950° C., T. 500° C. — As-rolled surface.	466	234	0–33
*N*3		Cyanide bath: 2 hr. at 850° C., O.Q. 850° C., T. 500° C. — As-rolled surface.	431 472	460 427	0–40 0–36
*N*4		Cyanide bath: 2 hr. at 850° C., O.Q. 850° C., T. 450° C. — As-rolled surface.	555	580	0–33
*N*5		Cyanide bath: 2 hr. at 850° C., O.Q. 850° C., Not tempered — As-rolled surface.	763	647	0–50
*O*1	Chromium-vanadium spring steel, *S*5.	Muffle: O.Q. 850° C., T. 600° C. — Machined and polished.	Brinell Hardness 385		0–56
*O*2		Muffle: O.Q. 850° C., T. 600° C. — As-rolled surface.	428	328	0–33
*O*3		Cyanide bath: 2 hr. at 850° C., O.Q. 850° C., T. 600° C. — As-rolled surface.	417	543	0–35
*O*4		Cyanide bath: 2 hr. at 850° C., O.Q. 850° C., T. 450° C. — As-rolled surface.	538	642	<0–35
*O*5		Cyanide bath: 2 hr. at 850° C., O.Q. 850° C., Not tempered — As-rolled surface.	766	716	0–60

machined and polished plates (test series *N*1). This rather disappointing result, which was checked by a duplicate series of tests, was to some extent anticipated, because the chance of striking a bad surface irregularity is much greater than in the case of the preliminary tests.

The fatigue results obtained on cyanide-treating chromium-vanadium steel (test series *O*3) are no more encouraging than those obtained on silico-manganese steel, but it was thought that the recarburised materials might show to better advantage if tempered at a lower temperature. Test-pieces tempered at 450° C. (test series *N*4 and *O*4) (instead of 500° C. for silico-manganese steel and 600° C. for chromium-vanadium steel) exhibited a higher hardness both in the core and on the surface, but the fatigue resistance was found to be no higher than that of the softer materials. Further series of tests (*N*5 and *O*5) were made on untempered specimens possessing a still higher hardness, and although material in this condition could not safely be used for springs, it is very interesting to note that the fatigue resistance showed a marked improvement, the value obtained being about the same as that given for normally treated plates in the machined and polished condition. These high results on untempered specimens were not explained, but in view of

later work on the effect of internal stresses[4] the suggestion is made that they might be attributed to the presence of surface compressive stresses which are set up during quenching, and which are not subsequently relieved by any tempering treatment.

Tests were then carried out on a carbon spring steel and a low-chromium spring steel, the compositions of which are given in Table I. The mechanical properties of these steels in the machined condition have been published.[5]

The recarburising treatment was the same for both steels, namely, immersion in a cyanide bath for 2 hr. at 850° C., after which the temperature of the bath was lowered to the appropriate quenching temperature—810° C. for the carbon steel, which was water-quenched, and 800° C. for the low-chromium steel, which was oil-quenched. In the case of the ordinary muffle treatment, the steels were heated to, and quenched from, the same temperatures as in the cyanide treatment, except that the low-chromium steel was not soaked at a temperature in excess of its quenching temperature (800° C.). The carbon steel was tempered at 500° C. and the low-chromium steel at 600° C. in order to compare the figures obtained with results yielded by the latter steel in the temper-stressed condition.[4]

TABLE VI.—*Summary of Results of Plane-Bending Fatigue Tests on Carbon and Low-Chromium Spring Steels.*

Test Series.	Steel.	Treatment.	Diamond Pyramid Hardness Number.		Limiting Range of Stress. Tons per sq. in.
			Interior.	Surface.	
*P*1	0·46% carbon spring steel, *S*8.	Muffle: ½ hr. at 850° C., W.Q. 810° C., T. 500° C. — As-rolled surface.	338	275	0–19
*P*2		Cyanide bath: 2 hr. at 850° C., W.Q. 810° C., T. 500° C. — As-rolled surface.	350	504	0–28 approx.
*Q*1	Low-chromium spring steel, *S*3.	Muffle: 1 hr. at 800° C., O.Q. 800° C., T. 600° C. — As-rolled surface.	382	225	0–25
*Q*2		Cyanide bath: 2 hr. at 850° C., O.Q. 800° C., T. 600° C. — As-rolled surface.	365	506	0–33

The results of the tests are given in Table VI. The fatigue range in the fully machined and polished condition was not determined, but from previous experience with material of similar hardness, it is safe to say that this would lie in the region of 0–50 tons per sq. in. Although comparing favourably with some commercial springs tested, the fatigue strength of the carbon steel in the muffle-treated condition (test series *P*1) is much lower than that of the two special alloy spring steels previously tested. This is probably due to the presence of irregularities and included oxide and scale defects

which appeared less evident in the higher-class materials. In this connection Fig. 4 shows typical sharp inclusions in an unetched section at the surface of the carbon steel. The improvement in fatigue resistance on recarburising the surface (test series *P*2) is quite marked in the case of this steel, in spite of the presence of the rolled-in slag, &c.

The endurance limit of the low-chromium steel in the muffle-treated condition (test series *Q*1) is distinctly superior to that of the carbon steel, but inferior to that of the silico-manganese and chromium-vanadium steels. After cyanide treatment the endurance limit of the low-chromium steel (test series *Q*2) is appreciably raised, and is then about equal to that of the two alloy steels in either the muffle- or cyanide-treated condition.

Recarburisation of Forgings.—In addition to the above experiments, relating to the influence of surface recarburisation on the fatigue strength of spring steel plate, a few rotating beam fatigue tests were carried out on recarburised forgings of a 0·2% carbon steel, a 0·4% carbon steel, a 3% nickel steel, and a 3% nickel, 0·75% chromium steel. The fatigue limit of these forgings in the commercially heat-treated condition ranged from about $\pm$ 12 tons per sq. in. for the material with the lowest tensile strength to about $\pm$ 18 tons per sq. in. for that with the highest.[6] After cyanide recarburisation, followed by the appropriate heat treatment, the fatigue range of all the forgings was raised to about $\pm$ 19 tons per sq. in., a value well in excess of the intrinsic value (polished condition) for mild steel, but much below the intrinsic value of about $\pm$ 31 tons per sq. in. obtained for the two higher tensile materials.

Tests on Spring Plates Machined on One Side.—In the foregoing tests in the plane-bending fatigue machine, it was repeatedly noticed that the fatigue fractures were initiated on the tension sides of the specimens. It was therefore concluded that in regard to fatigue the condition of the tension side of the specimen is of paramount importance, whilst that of the compression side is comparatively immaterial. Actual tests on spring plates (test series *R*1 and *R*2 in the Appendix, Section IIB.), in which the tension side only was machined, indicated an endurance limit of about 0–47 tons per sq. in. for silico-manganese steel (*S*6) and 0–50 tons per sq. in. for 0·46% carbon steel (*S*8). In every instance the fatigue cracks were developed from the machined tension side of the specimens, and not from the rough compression side. The results of the tests therefore substantiate the above conclusion, for when the tension side of a specimen is machined and polished, a high fatigue value is obtained, irrespective of the condition of the compression side.

Conclusion, Section II. (*Recarburising Experiments*).

It is difficult to explain the whole of the fatigue results on the recarburised specimens in a logical manner. The silico-manganese and chromium-vanadium steels were high quality materials in which

surface decarburisation occurred but irregularities and inclusions were hardly noticeable. Accordingly, the recarburisation would be expected to give a definite increase in the fatigue resistance; this, however, was not the case. The high fatigue resistance of these steels when recarburised and not tempered is surprising, but this may be due to the effect of internal stresses. The carbon steel and the low-chromium steel were decarburised and contained surface irregularities and inclusions; elimination of the decarburisation gave improved fatigue resistance, and this agrees with the results of Section I. of the present paper, in which it is shown that the notch alone gives a higher fatigue resistance than the notch and decarburisation combined. In general, the results suggest that surface recarburising is likely to be of little value on high quality steels which give comparatively good fatigue results in the unmachined condition without special treatment, but that it may be useful on average steels which give much lower results in the ordinary unmachined heat-treated condition.

Section III.

Fatigue Tests on Unmachined Forgings of High-Tensile Steels.

In a previous paper [6] it has been shown that the effect of the unmachined surface on the fatigue resistance of steel forgings may be very marked. The effect is small for mild steel, but for alloy steels having a tensile strength of about 60 tons per sq. in., the limiting fatigue stress in the as-forged condition is only about one-half of the intrinsic fatigue limit of the material. It is not unreasonable to suppose that the effect of the forged surface may be even more marked in a steel of still higher tensile strength.

Accordingly, the previous investigation of the fatigue strength of unmachined steel forgings has been extended to include steels of over 100 tons per sq. in. ultimate tensile stress. Two batches of heat-treated forgings were obtained from different steel makers. One material was a nickel-chromium-molybdenum steel and the other was a nickel-chromium steel. The chemical analyses of the steels are given in Table VII.

Table VII.—*Composition of High-Tensile Forgings.*

Manufacturer.	C. %.	Si. %.	Mn. %.	S. %.	P. %.	Ni. %.	Cr. %.	Mo. %.
B . . .	0·32	0·27	0·61	0·006	0·007	3·49	0·75	...
C . . .	0·41	0·28	0·62	0·032	0·019	2·53	0·63	0·63

Preliminary Mechanical Tests.—Tensile, diamond pyramid hardness, and notched-bar impact (Izod) tests were carried out on both steels.

The tensile tests and notched-bar impact tests were made on

representative forgings of each batch, while the hardness tests were made on all specimens to check their uniformity. The Izod tests were made on round specimens, but since the diameter of the forgings was only large enough to obtain specimens 0·42 in. in dia. instead of the standard 0·45 in., the results are somewhat lower than would be obtained from standard size specimens.

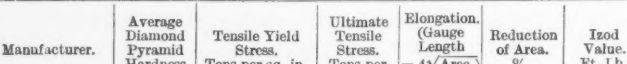
Diamond pyramid hardness tests were at first made on the large end of each forging, but as it was noticed that the hardness varied along the length of individual forgings of the batch supplied by manufacturer *C*, further tests were made on the small diameter central portion of the forging, after the fatigue tests had been carried out; the results of the latter series of tests were taken as representing the hardness of the material.

The results of the preliminary mechanical tests are given in Table VIII. They indicate high-quality material as judged by normal mechanical tests.

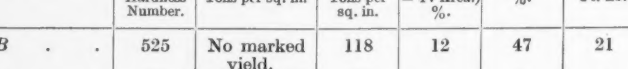
TABLE VIII.—*Mechanical Properties of High-Tensile Forgings.*

Manufacturer.	Average Diamond Pyramid Hardness Number.	Tensile Yield Stress. Tons per sq. in.	Ultimate Tensile Stress. Tons per sq. in.	Elongation. (Gauge Length $= 4\sqrt{\text{Area.}}$) %.	Reduction of Area. %.	Izod Value. Ft. Lb.
B . .	525	No marked yield.	118	12	47	21
C . .	580	No marked yield.	138	12	34	14

Fatigue Tests.—The forms of the forgings used in the tests were the same as those used in the previous investigation, and are shown in Fig. 3. The centre portions of test-pieces of type (*a*) were not



Test-piece type (*a*) - Unmachined.



Test-piece type (*b*) - Machined and polished

FIG. 3.—Forms of Forged Test-Pieces.

machined or polished (except for filing off longitudinal fins produced in the forging operations in specimens from manufacture *B*), the diameter of the central portion being about 0·34 and 0·32 in. for

forgings from manufacturers *B* and *C* respectively. The centre portions of test-pieces of type (*b*) were machined down to 0·250 in. in dia. and finished by polishing down to No. 00 blue-back emery paper. This is the normal surface finish used in fatigue tests at the Laboratory. Six polished specimens and eight representative as-forged specimens were tested from each batch.

Rotating bending fatigue tests were carried out under a uniform bending moment at 3000 stress cycles per min., the endurance basis being 10^7 stress reversals.

Table IX. gives a summary of the results of the fatigue tests; detailed results are given in the Appendix, Section III. The ratio of the fatigue strengths of as-forged and polished specimens, and the ratios of fatigue strengths to the ultimate tensile stresses are also given in the Table.

TABLE IX.—*Summary of Fatigue Test Results.*

Manufacturer.	Tensile Strength. Tons per sq. in. (1)	Endurance Fatigue Limit. Tons per sq. in.		Ratio Col. (2) / Col. (3) (4)	Ratio Col. (2) / Col. (1) (5)	Ratio Col. (3) / Col. (1) (6)
		As-Forged. (2)	Machined and Polished. (3)			
B . .	118	±9·4	±49·5	0·19	0·08	0·42
C . .	138	±8·3	±49·5	0·17	0·06	0·36

The fatigue strength of the as-forged specimens is seen to be very low, not only in relation to that of polished specimens of the same steel, but also in comparison with the fatigue strength of other forged steels; it is, in fact, lower than that of mild steel forgings previously tested.

In consequence of the very great effect of the surface on these steels, it was thought that perhaps even the surface finish of the machined and polished specimens (No. 00 blue-back emery paper) was not sufficiently good to allow the full intrinsic fatigue strength of the material to be developed. This suggestion is supported by the values given in column (6) of Table IX. The ratio of limiting fatigue stress under reversed bending stresses to the ultimate tensile stress is in the neighbourhood of 0·5 for the majority of steels, whereas these steels apparently give ratios of only 0·42 and 0·36.

In order to test this it was decided to repeat the fatigue tests on machined and polished specimens, giving the central portion of each specimen a very high polish. The final polishing of these test-pieces was done with No. 0000 blue-back emery paper, rubbing in a longitudinal direction until all traces of the circumferential scratches left by the previous coarser emery paper had disappeared. The main results of tests on these highly polished specimens are given in Table X., and detailed results in the Appendix, Section III.

It is evident that the scratches left by the normal polishing

TABLE X.—*Fatigue Tests on Highly Polished Specimens.*

Manufacturer.	Ultimate Tensile Stress. Tons per sq. in.	Endurance Fatigue Limit. Tons per sq. in.	Ratio.
B	118	±52·5	0·445
C	138	±65	0·47

method used for fatigue specimens, although quite unimportant in the case of ordinary steels, are sufficient to reduce the fatigue limit of these very hard steels. This effect is particularly marked with the higher tensile steel from manufacturer *C*.

Surface Hardness Tests and Microstructure.—In order to examine the hardness of the surface of the forgings, standard diamond pyramid hardness tests were made on the test-pieces used for fatigue tests in the unmachined condition. The only preparation the surface received for the hardness tests was a light polishing with fine emery paper, and the tests were made with a small load, 5 kg., on the diamond. The hardness values obtained are given in Table XI., the results indicating that the surface of the forgings, although quite hard, is considerably softer than the interior.

TABLE XI.—*Diamond Pyramid Hardness Tests.*

Manufacturer.	Average Diamond Pyramid Hardness Numbers.		
	Surface.	Interior.	Difference.
B	357	525	168
C	438	580	142

The microstructure of the original forgings was found to be uniformly martensitic ; this is seen in Fig. 8 (Plate XXXVII.), which shows a subsidiary transverse fatigue crack produced in testing a specimen supplied by manufacturer *C*. A section of a forging (manufacturer *B*) after normalising from 900° C. is illustrated in Fig. 10 (Plate XXXVIII.). The carbon content of these steels is much lower than that of spring steels, and it is therefore not surprising that decarburisation is not so noticeable.

The degree of surface softness exhibited by these high tensile forgings could not account directly for their exceedingly low fatigue strength, and in order to obtain further information, additional tests were made on forgings which had been completely machined and then again heat-treated by oil-quenching from a muffle furnace (held at 930° C. for 15 min.) and tempering at 300° C. in a salt bath. This treatment was intended to reproduce the general mechanical properties of the original forgings, but since the surfaces had been machined prior to the final heat treatment, any surface deterioration was confined to the effects of that final heat treatment. The tests

FIG. 4.—Sharp Inclusions in Rolled Surface of 0·46% Carbon Spring Steel S8. × 300.

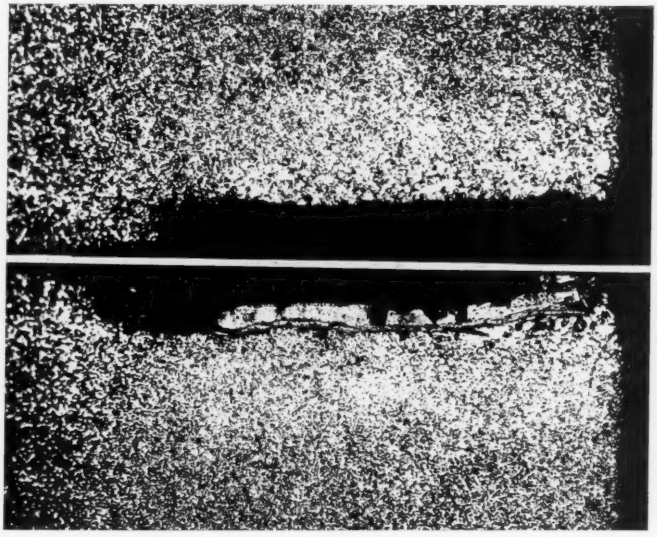


FIG. 5.—Spring Steel Fatigue Test-Piece, showing two sides of artificial crack after fracture. × 300.

(Micrographs reduced to four-fifths linear in reproduction.)

[*Hankins, Becker, and Mills.*

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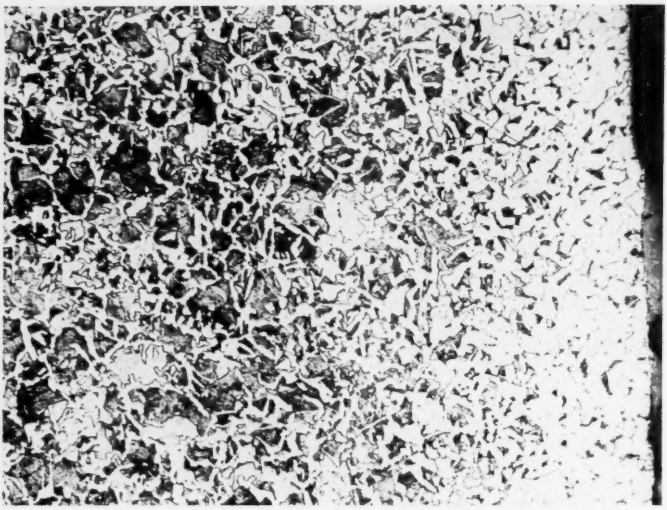

FIG. 6.—Steel containing 0·46% of Carbon, as rolled, showing decarburisation. × 150.

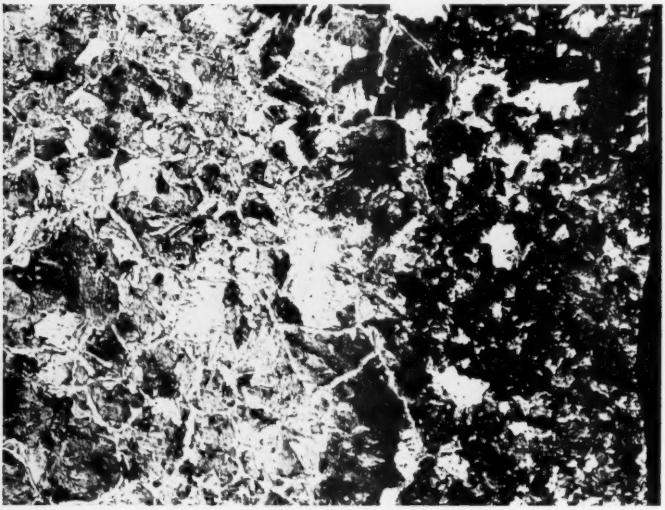

FIG. 7.—Steel containing 0·46% of Carbon. Recarburised in cyanide at 850° C. for 1 hr., followed by cooling in air. × 150.

(Micrographs reduced to four-fifths linear in reproduction.)

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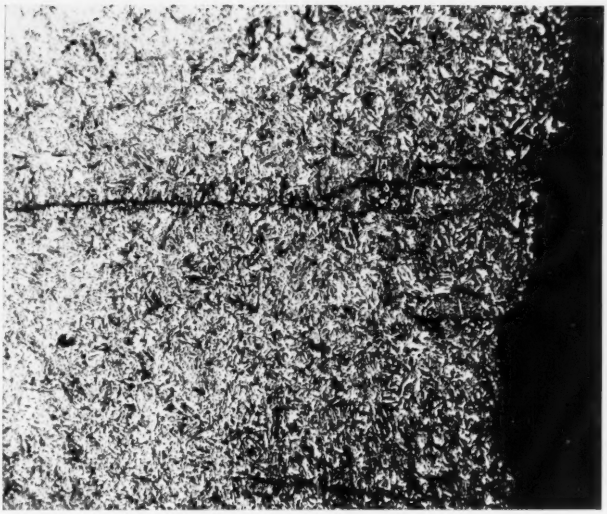

FIG. 8.—Heat-Treated High-Tensile Forging, showing subsidiary fatigue crack. × 150.

FIG. 9.—Section through a Surface Flaw in Rolled Mild Steel Plate. × 150.
(Micrographs reduced to four-fifths linear in reproduction.)
[*Hankins, Becker, and Mills.*

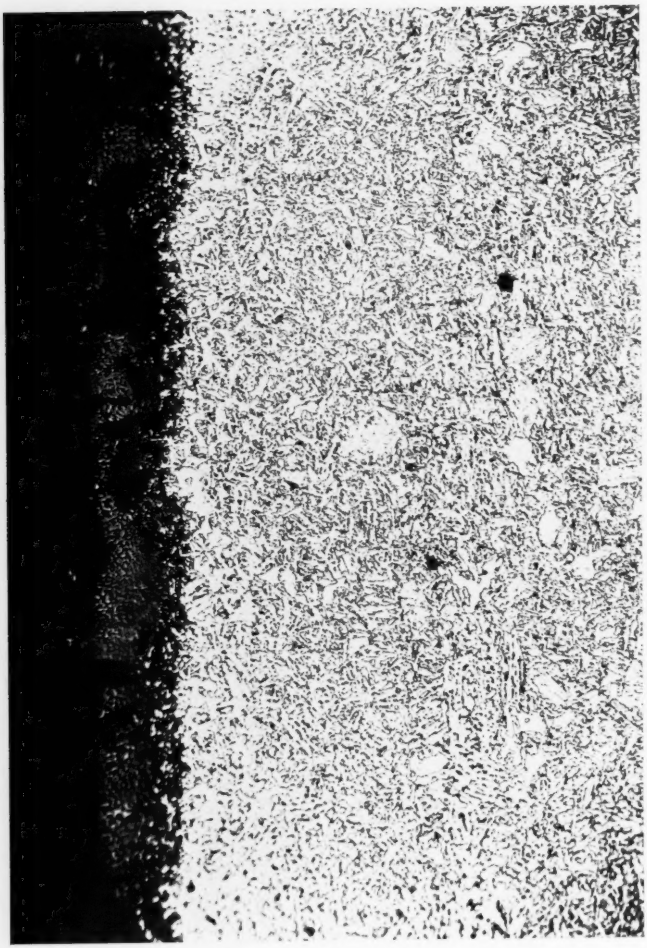

FIG. 10.—High-Tensile Forging (Manufacturer *B*) after normalising at 900° C., showing scale on surface. × 150.

[*Hankins, Becker, and Mills.*

[*To face p.* 417 P.

in this condition resulted in endurance fatigue limits of ± 28 tons per sq. in. for the forgings from manufacturer *B* and ± 32 tons per sq. in. for those from manufacturer *C*. (For details see Appendix, Section III.) These values, whilst very much higher than those obtained from the original unmachined forgings, are still only about one-half those for the same steels in the fully machined and polished condition (*see* Table IX.). Hardness tests, however, showed the heat-treated surfaces to be only slightly less hard than the main body of the materials.

Conclusion, Section III. (High Tensile Forgings).

The results obtained on the high tensile forgings are in general agreement with the work on spring steels, and indicate that the low fatigue resistance of the original forgings (Table IX.) is due to a combination of surface irregularities of shape and a defective surface layer caused by exposure to high temperatures during forging and heating. In this case, however, no positive evidence has been obtained that the defective surface layer is primarily due to decarburisation.

The immediate conclusion drawn from the present tests is that it is most inadvisable for very high tensile forgings to be subjected to fatigue stresses in service when the surfaces are in the as-forged heat-treated condition.

Section IV.

The Fatigue Resistance of Unmachined Rolled Mild Steel.

Rotating bending fatigue tests, previously carried out at the National Physical Laboratory on rolled mild steel plate,[6] indicated that the rolled surface had little effect upon the fatigue strength of the plate.

Subsequent tests on mild steel plates in the plane-bending fatigue testing machine have shown that under conditions of repeated bending stress the surface effect is somewhat more marked than under reversed stresses, though the reduction in fatigue resistance is still much less than for spring steels. Results for two samples of rolled mild steel from different sources are given in Table XII.

Table XII.—*Fatigue Tests on Rolled Mild Steel.*

Identification Mark.	Material.	Yield Stress. Tons per sq. in. (1)	Ultimate Tensile Stress. Tons per sq. in. (2)	Limiting Safe Range of Stress. Tons per sq. in.		Ratio Col. (3) / Col. (4)
				As-Rolled. (3)	Machined and Polished. (4)	
FJB .	Rolled mild steel bar.	19	31	0–21	...	...
GTP .		...	...	0–21·5	0–28	0·77

It should be noted that in these tests the upper limit of stress of the fatigue range is in excess of the yield point of the material, the machined and polished specimens developing an appreciable permanent set during the test. The stress values for the fatigue tests are calculated from the curvature of the plates, assuming elastic conditions.

The above results are typical of mild steel having a normal rolled surface, but for a mild steel with a bad surface containing flaws or non-metallic inclusions the fatigue resistance may be appreciably lower. A steel of the latter type was encountered during the course of an investigation on the fatigue strength of welds, and the results are included here as an example of the effect of really bad surface flaws in rolled mild steel. The fatigue tests were made in a Haigh direct-stress fatigue-testing machine using repeated tensile stresses. A number of small cracks developed in the surface of the plate during the tests, these cracks appearing to start at surface flaws. A section of the plate which had not been subjected to fatigue tests was examined, and a number of long surface flaws were found, one of which is shown in section in Fig. 9. The flaw appears to have been caused by a defect in the original ingot or by the rolling-in of mill scale. The limiting fatigue stress of this steel in the machined and polished condition was 0–15 tons per sq. in. in tension, while in the as-rolled condition it was less than 0–4½ tons per sq. in., or only 30% of the intrinsic fatigue strength. The maximum permissible working stress on this steel (structural steel Class *A*, British Standard Specification No. 15) is normally 8 tons per sq. in. It appears, however, that mild steel plates exhibiting bad surface flaws of this nature are very rarely encountered.

Conclusion, Section IV. (Unmachined Rolled Mild Steel).

It is concluded that the effect of the unmachined surface on the fatigue resistance of rolled mild steel is not very important, although exceptions can occur.

ACKNOWLEDGMENTS.

The work described has been carried out as an item of research financed by the Department of Scientific and Industrial Research and supervised by the Executive Committee of the National Physical Laboratory; the authors desire to record their appreciation of the opportunities afforded for carrying out the work and for permission to publish the results.

The authors desire to acknowledge the help and encouragement given by Dr. H. J. Gough, F.R.S. (Superintendent of the Engineering Department, National Physical Laboratory), and Dr. C. H. Desch, F.R.S. (Superintendent of the Metallurgy Department, National Physical Laboratory), during the progress of the work. They also wish to record the valuable assistance given by Mr. R. H. Spencer in much of the routine heat treatment and microscopical work.

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[APPENDIX FOLLOWS.]

APPENDIX.

SECTION I.—*Detailed Results of Rotating Bending Fatigue Tests.*

Test Series.	Material.	Treatment.	Specimen No.	Stress at Surface of Specimen. Tons per sq. in.	No. of Reversals (Millions).	Endurance Fatigue Limit. Tons per sq. in.
B	Chromium-vanadium steel, *S5*.	Ordinary heat treatment in muffle furnace. Unpolished.	*Z22A*	±33·4	0·08 B	±31
			Z22C	±31·4	0·18 B	
			Z22D	±31·3	0·13 B	
			Z22F	±30·4	12·20 U	
			Z22E	±29·6	11·42 U	
			Z22B	±28·7	11·33 U	
B	Silico-manganese steel, *S6*.	Ordinary heat treatment in muffle furnace. Unpolished.	*Q11F*	±31·9	0·06 B	Approx. ±24
			Q11C	±28·9	0·16 B	
			Q11B	±26·7	0·18 B	
			Q11D	±25·2	0·16 B	
			Q11E	±24·7	0·23 B	
			Q11A *	±23·9	16·51 U	
			Q11A	±20·4	9·63 U	
C	Chromium-vanadium steel, *S5*.	Heat-treated, machined and polished, and notched.	*Z1A* *	±24·5	0·18 B	±19·5 (±22·4 when corrected for depth of notch).
			Z1B	±21·6	0·57 B	
			Z1D *	±21·6	0·35 B	
			Z1C	±20·2	0·17 B	
			Z1A	±19·0	9·69 U	
			Z1D	±16·2	9·06 U	
C	Silico-manganese steel, *S6*.	Heat-treated, machined, polished, and notched.	*V4A* *	±22·7	0·83 B	±20·5 (±23·5 when corrected for depth of notch).
			V4F	±20·6	9·76 U	
			V4B	±20·5	0·66 B	
			V4E	±20·3	10·78 U	
			V4D	±19·9	12·39 U	
			V4C	±19·3	11·61 U	
			V4A	±18·2	11·96 U	
D	Chromium-vanadium steel, *S5*.	Machined and notched. Then heat-treated.	*Z23C*	±18·0	0·23 B	±17·2 (±19·8 when corrected for depth of notch).
			Z23A	±17·4	0·20 B	
			Z23E	±17·1	10·30 U	
			Z23B	±16·7	10·21 U	
			Z23D	±15·8	10·33 U	
			Z23F	±14·4	18·88 U	
D	Silico-manganese steel, *S6*.	Machined and notched. Then heat-treated.	*V3A* *	±20·2	0·09 B	Approx. ±16 (±18·5 when corrected for depth of notch).
			V3B	±17·4	0·12 B	
			V3D	±16·8	0·27 B	
			V3E	±16·6	0·31 B	
			V3C	±16·3	10·30 U	
			V3F	±16·0	0·32 B	
			V3A	±15·1	10·00 U	
E	Chromium-vanadium steel, *S5*.	Decarburised and heat-treated. Lightly polished.	*M9*	±21·1	2·50 B	±20·8
			M16	±20·9	0·34 B	
			M14	±20·7	11·50 U	
			M12	±19·9	11·49 U	
F	Chromium-vanadium steel, *S5*.	Decarburised and heat-treated. Unpolished.	*K12A*	±20·1	0·44 B	±18·0
			K12C	±18·5	1·11 B	
			K12E	±17·8	11·52 U	
			K12D	±17·2	11·18 U	
			K12B	±16·0	14·96 U	

SECTION I.—*Detailed Results of Rotating Bending Fatigue Tests (continued).*

Test Series.	Material.	Treatment.	Specimen No.	Stress at Surface of Specimen. Tons per sq. in.	No. of Reversals (Millions).	Endurance Fatigue Limit. Tons per sq. in.
G	Chromium-vanadium steel, *S5*.	Decarburised and heat-treated. Then notched.	*M19*	±17·5	0·12 B	±13·5 (±15·5 when corrected for depth of notch).
			M11	±14·6	0·20 B	
			M10	±13·7	8·22 B	
			M20	±13·6	10·89 B	
			M13	±13·0	16·82 U	
G	Silico-manganese steel, *S6*.	Decarburised and heat-treated. Then notched.	*V2F*	±14·9	0·26 B	Approx. ±10 (±11·5 when corrected for depth of notch).
			V2B	±14·0	0·15 B	
			V2C *	±11·9	1·18 B	
			V2D	±11·6	0·55 B	
			V2A	±11·0	0·29 B	
			V2C	±10·5	15·00 U	
			V2E	± 8·8	0·57 B	
H	Chromium-vanadium steel, *S5*.	Decarburised and notched. Then heat-treated.	*Z21C* *	±17·4	0·18 B	±15·8 (±18·2 when corrected for depth of notch).
			Z21E	±16·1	0·23 B	
			Z21D	±15·6	11·83 U	
			Z21F	±14·6	11·60 U	
			Z21C	±11·6	12·10 U	
H	Silico-manganese steel, *S6*.	Decarburised and notched. Then heat-treated.	*V1D*	±12·2	0·17 B	Approx. ±10 (±11·5 when corrected for depth of notch).
			V1B *	±11·7	1·31 B	
			V1C *	±11·3	0·35 B	
			V1F *	±11·0	0·99 B	
			V1B	±10·5	9·28 U	
			V1E	± 9·8	0·72 B	
			V1F	± 9·4	11·67 U	
			V1C	± 8·8	11·01 U	
I	Chromium-vanadium steel, *S5*.	Sharply notched and notch closed by pressure while hot. Then heat-treated and surface machined (artificial "cracks").	*Z25D*	±15·2	0·29 U †	±9·5 (±12 when corrected for depth of notch).
			Z25E	±15·0	0·06 B	
			Z25C	±14·6	0·32 U †	
			Z24A	±11·9	0·38 B	
			Z24D	±10·5	0·30 B	
			Z25F *	±10·4	1·08 B	
			Z24F	± 9·7	1·36 B	
			Z25A	± 9·3	0·38 B ‡	
			Z25F	± 8·9	11·65 U	
J	Chromium-vanadium steel, *S5*.	Artificial "cracks" made as above, but heated in muffle for ½ hr. before closing notch. (Decarburised at bottom of notch.) Then heat-treated and surface machined.	*M23C* *	±11·3	11·83 U	±10·3 (±12·2 when corrected for depth of notch).
			M23B *	±11·2	0·26 B	
			M23F	±10·6	0·71 B	
			M23D	±10·5	0·41 B	
			M23C	±10·1	11·39 U	
			M23E	± 9·7	14·39 U	
			M23B	± 9·4	11·87 U	

B = Broken. U = Unbroken.
* Previously "understressed" by running for 10^7 reversals at lower stress.
† Broke in chuck of testing machine.
‡ Cracked at bottom of notch before testing.

SECTION IIA.—*Detailed Results of Tests on Rotating Bending Fatigue Test-Pieces with Flats.*

Test Series.	Material.	Treatment.	Specimen No.	Stress Range. Tons per sq. in.	No. of Reversals (Millions).	Endurance Fatigue Limit. Tons per sq. in.
K	Silico-manganese steel, *S*6.	O.Q. 950° C., T. 500° C., then machined and polished on both flats.	*S6T13C* *	±48·0	0·33 B	±45
			S6T13C	±45·0	12·73 U	
			S6T13B	±43·0	0·25 U †	
			S6T10B *	±41·8	8·00 U	
			S6T10C	±36·1	0·24 B ‡	
			S6T10B	±34·6	10·76 U	
L		O.Q. 950° C., T. 500° C., one flat as-rolled.	*S6T9A*	±32·2	0·21 B	±25
			S6T9E	±28·5	0·77 B	
			S6T9C *	±27·1	0·30 B	
			S6T10A	±25·6	1·28 B	
			S6T9C	±25·1	12·77 U	
M		Heated in cyanide bath for 2 hr. at 850° C., then heat-treated (O.Q. 850° C., T. 500° C.), one flat as-rolled.	*S6U8D*	±44·7	0·025 B	Approx. ±40
			S6U7C *	±44·5	0·19 B	
			S6U6C *	±43·6	0·16 B	
			S6U7B	±42·2	0·13 B	
			S6U8A	±40·8	0·08 B	
			S6U6B	±40·5	0·38 B	
			S6U6A	±40·5	2·49 B	
			S6U7C	±40·2	11·81 U	
			S6U6C *	±39·5	10·24 U	
			S6U7D	±37·6	0·28 B ‡	
			S6U8B	±36·4	0·10 B	
			S6U6C	±34·5	10·42 U	

SECTION IIB.—*Detailed Results of Plane Bending Fatigue Tests.*

Test Series.	Material.	Treatment.	Specimen No.	Stress Range. Tons per sq. in.	No. of Stress Cycles (Millions).	Limiting Safe Range of Stress. Tons per sq. in.
*N*1	Silico-manganese steel, *S*6.	O.Q. 950° C., T. 500° C. Machined and polished.	*S6S3*	0–60	1·27 B	0–55
			S6S1	0–57	0·60 B	
			S6S2 *	0–57	5·69 U	
			S6S2	0–53	6·25 U	
*N*2		O.Q. 950° C., T. 500° C.	*S6P12*	0–37	0·15 B	0–33
			S6P8	0–36	0·89 B	
			S6P14	0–35	0·72 B	
			S6P7	0–34	0·26 U †	
			S6P11	0–30	20·00 U	
*N*3		2 hr. in sodium cyanide bath at 850° C. O.Q. 850° C., T. 500° C.	*S6R2*	0–50	0·06 B	0–40
			S6R4	0–45	0·10 B	
			S6R3	0–40	6·00 U	
*N*3 (Repeat series)		2 hr. in sodium cyanide bath at 850° C., O.Q. 850° C., T. 500° C.	*S6V5*	0–40	0·10 B	0–36
			S6V8	0–38	0·32 B	
			S6V7	0–37	0·11 B	
			S6V6	0–36	7·00 U	
*N*4		2 hr. in sodium cyanide bath at 850° C. O.Q. 850° C., T. 450° C.	*S6W6*	0–50	0·02 B	0–33
			S6W4	0–40	0·10 B	
			S6W5 *	0–37	0·13 B	
			S6W5	0–30	12·93 U	
*N*5		2 hr. in sodium cyanide bath at 850° C. O.Q. 850° C. Not tempered.	*S6W1*	0–60	0·04 B	0–50
			S6W3	0–55	0·02 B	
			S6W2	0–50	5·80 U	

SECTION IIB.—*Detailed Results of Plane Bending Fatigue Tests (continued).*

Test Series.	Material.	Treatment.	Specimen No.	Stress Range. Tons per sq. in.	No. of Stress Cycles (Millions).	Limiting Safe Range of Stress. Tons per sq. in.
O1	Chromium-vanadium steel, *S5*.	O.Q. 850° C., T. 600° C. Machined and polished.	*S5L5*	0–60	0·31 B	0–56
			S5L2 *	0–60	0·40 B	
			S5L3	0–57	0·23 B	
			S5L2	0–55	6·01 U	
O2		O.Q. 850° C., T. 600° C.	*S5H7*	0–40	0·18 B	0–33
			S5H9	0–35	0·23 B	
			S5H10	0–33	1·13 U †	
			S5H8	0–32	4·67 U	
			S5H6	0–26	1·31 U †	
O3		2 hr. in sodium cyanide bath at 850° C. O.Q. 850° C., T. 600° C.	*S5AA2*	0–37	0·08 B	0–35
			S5AA6	0–36	1·26 B	
			S5AA4 *	0–36	6·47 U †	
			S5AA4	0–33	6·00 U	
O4		2 hr. in sodium cyanide bath at 850° C. O.Q. 850° C., T. 450° C.	*S5Z15*	0–50	0·02 B	<0–35
			S5Z17	0–40	5·31 B	
			S5Z16	0–35	0·08 B	
O5		2 hr. in sodium cyanide bath at 850° C. O.Q. 850° C. Not tempered.	*S5Z12* *	0–60	2·32 B	0–60
			S5Z14	0–60	6·74 U	
			S5Z13	0–55	6·57 U	
			S5Z12	0–50	6·19 U	
P1	0·46% carbon steel, *S8*.	15 min. in muffle furnace at 850° C. Cooled in furnace to 810° C. W.Q. 810° C., T. 500° C.	*S8F6*	0–25	0·23 B	0–19
			S8F7	0–20	1·60 B	
			S8F8	0–17	8·34 U	
P2		2 hr. in sodium cyanide bath at 850° C. Cooled to 810° C. in bath. W.Q. 810° C., T. 500° C.	*S8F3* *	0–40	0·08 B	Approx. 0–28
			S8F2	0–40	0·16 B	
			S8F4	0–32	0·08 B	
			S8F3	0–30	7·75 U	
			S8F5	0–28	0·13 B	
Q1	Low-chromium steel, *S3*.	1 hr. in muffle furnace at 800° C. O.Q. 800° C., T. 600° C. (air-cooled).	*S3U1*	0–30	0·34 B	0–25
			S3U3	0–28	0·38 B	
			S3U4	0–27	0·46 B	
			S3U5	0–26	0·61 B	
			S3U2	0–25	6·08 U	
			S3U6	0–25	7·07 U	
Q2		2 hr. in sodium cyanide bath at 850° C. Cooled in bath to 800° C. O.Q. 800° C., T. 600° C. (air-cooled).	*S3U8* *	0–40	0·06 B	0–33
			S3U9	0–36	0·04 B	
			S3U10	0–34	0·18 B	
			S3U8	0–33	7·34 U	
R1	Silico-manganese steel, *S6*.	O.Q. 950° C., T. 500° C. Machined and polished only on tension face and edges.	*S6W10*	0–50	1·50 B §	Approx. 0–47
			S6W7	0–50	0·59 B	
			S6W11 *	0–48	0·18 B	
			S6W9	0–45	1·83 B §	
			S6W12	0–45	7·69 U	
			S6W11	0–42	5·83 U	
R2	0·46% carbon steel, *S8*.	W.Q. 810° C., T. 500° C. Machined and polished only on tension face and edges.	*S8G1*	0–60	0·08 B	0–50
			S8G2	0–55	0·12 B	
			S8G3	0–52	6·14 B	
			S8G5	0–51	2·87 B	
			S8G6	0–50	7·13 U	
			S8G4	0–40	6·19 U	

B = Broken. U = Unbroken.
* Previously "understressed."
† Broken in grips of testing machine.
‡ Broken at flaw or crack in material.
§ Edges of specimen not machined and polished.

SECTION III.—*Detailed Results of Rotating Beam Fatigue Tests on High-Tensile Forgings.*

Condition.	Manufacturer.	Specimen No.	Stress Range. Tons per sq. in.	No. of Reversals (Millions).	Endurance Fatigue Limit. Tons per sq. in.
As-forged	*B*	5*B*33	±20·1	0·10 B	± 9·4
		77	±17·0	0·17 B	
		10	±14·9	0·25 B	
		13	±13·0	0·48 B	
		14	±10·9	1·06 B	
		18	±10·0	1·55 B	
		19	± 9·6	<4·5 B	
		17	± 9·1	9·91 U	
As-forged	*C*	5*C* 3	±14·9	0·28 B	± 8·3
		12	±12·1	0·73 B	
		24	±10·1	0·70 B	
		14	± 9·0	1·26 B	
		15	± 8·6	1·50 B	
		23	± 8·4	<3·88 B	
		25	± 8·2	10·06 U	
		11	± 8·0	9·97 U	
Ordinary polish	*B*	5*B*26	±52	1·16 B	Approx. ±49·5
		2	±50·5	4·61 B	
		6	±49·5	12·64 B	
		8	±49·5	0·88 U †	
		4	±48·5	10·03 U	
		11	±45	10·05 U	
Ordinary polish	*C*	5*C* 2	±51	2·90 B	Approx. ±49·5
		6	±50	9·97 B	
		8	±49·5	0·48 B	
		21	±49·5	15·45 U	
		10	±49	15·07 U	
		9	±48·5	10·02 U	
High polish	*B*	5*B*16	±58	0·88 U †	Approx. ±52·5
		24	±58	0·79 B	
		20	±55	2·08 B	
		23	±54·5	8·55 B	
		1	±53	5·33 B	
		2	±53	8·83 B	
		12	±50	10·11 U	
High polish	*C*	5*C* 7 *	±67·5	0·12 B	Approx. ±65
		22	±65	12·36 B	
		19	±62·5	11·59 U	
		4	±55·5	11·61 U	
		18	±51	0·34 U †	
		7	±50·5	9·63 U	
Completely machined and polished, then O.Q. 950° C., T. 300° C. No machining or polishing subsequent to heat treatment.	*B*	*B* 4 *	±30·1	0·11 B	±28
		12	±29·6	0·15 B	
		17	±27·7	10·02 U	
		11	±25·1	12·01 U	
		4	±20·1	10·02 U	
	C	*C* 9	±34·7	0·24 B	±32·5
		19	±33·7	6·65 B	
		22	±33·0	0·74 B	
		21	±32·3	15·16 U	
		10	±30·1	11·66 U	

* Previously "understressed."
† Broke in chuck of testing machine.

SECTION IV.—*Detailed Results of Repeated Plane-Bending Fatigue Tests on Rolled Mild Steel.*

Reference Mark.	Condition.	Specimen No.	Stress Range. Tons per sq. in.	No. of Stress Cycles (Millions).	Limiting Safe Range of Stress. Tons per sq. in.
FJB	As-rolled.	*FJB*18 *	0–26	1·06 B	0–21
		19	0–24	0·78 B	
		20	0–22	1·29 B	
		18	0–20	6·13 U	
		17	0–20	1·73 U †	
		2	0–18	6·33 U	
		1	0–15	5·00 U	
GTP	As-rolled.	*GTP* 3	0–25	0·75 B	0–21·5
		2	0–22	5·38 B	
		5	0–21	8·01 U	
		4	0–20	6·32 U	
GTP	Machined and polished.	*GTP*10 *	0–30	1·94 B	0–28
		7	0–29	2·40 B	
		8	0–28	7·71 U	
		6	0–27	6·22 U	
		10	0–25	5·83 U	

B = Broken. U = Unbroken.
* Previously "understressed."
† Broken in grip of testing machine.

[This paper was discussed jointly with the following one by Becker and Phillips.]

INTERNAL STRESSES AND THEIR EFFECT ON THE FATIGUE RESISTANCE OF SPRING STEELS.*

By M. L. BECKER, B.Met., Ph.D., and C. E. PHILLIPS, A.C.G.I., D.I.C. (National Physical Laboratory).

Summary.

This work is part of a comprehensive investigation carried out at the National Physical Laboratory on the effects of surface conditions on the fatigue resistance of steels. Methods of improving the fatigue resistance of unmachined steels are also included in the programme.

Preliminary internal stress measurements were carried out on a silico-manganese steel, a 0·6% carbon steel, and a 5% nickel steel case-hardened. It was found that quenching from the tempering temperature induced compressive stresses near the surface of a spring plate. Fatigue tests were carried out on chromium-vanadium and low-chromium steels, with various conditions of surface, to determine the effect of such internal stresses. A few tests were carried out to determine the effect of scragging (*i.e.*, giving a permanent deflection by controlled overloading) on the fatigue resistance of spring plates.

The fatigue resistance of spring plates subjected to bending stresses can be improved by "temper-stressing," *i.e.*, quenching in water from the tempering temperature, and this improvement is considered to be due to the presence of compressive surface stresses which cause a reduction in the tensile stress on the tension side of the plates, particularly at the roots of surface irregularities. The scragging of springs is beneficial to their fatigue resistance and this again appears to be due to residual compressive stresses in the tension surfaces.

Introduction.

The influence of surface conditions on the fatigue resistance of heat-treated spring steels is now well known, and the adverse effects of surface decarburisation and surface irregularities of shape have already been studied together with the advantages to be gained from the recarburisation of rolled spring plate.[1-4]

The present paper describes an investigation carried out with the object of determining whether internal stresses of appreciable magnitude occur near the surface of heat-treated steels, and, if so, whether such stresses affect the fatigue properties. Preliminary experiments having indicated that high compressive stresses may be induced by suitable heat treatment, attempts have been made to apply such treatments to rolled, unmachined spring steel plates, with the object of improving their fatigue resistance.

* Communication from the National Physical Laboratory, received February 20, 1936.

The investigation has been carried out at the National Physical Laboratory as part of the programme of work on the effect of surface conditions on the fatigue resistance of steels.

Internal Stress Measurements on Rolled Bars.

The estimation of internal stresses in materials, even of simple form, presents complex problems, the solution of which requires very great precision in measurement, together with accurate control of working conditions. Throughout this investigation, attempts have been made to obtain rough estimates with relative, rather than actual values of internal stress.

For the purposes of internal stress measurements, $1\frac{1}{8}$ in. dia. bars of silico-manganese and 0·6% carbon steels * were selected, and of the various published methods [5] of measurement, it was decided to use that originally devised by Professor Heyn [6] and later used by other investigators.[7, 8] The internal stresses were assumed to be longitudinal, and no account has been taken of radial and circumferential stresses. The method involves measuring the change in length of a specimen due to the removal, by careful machining, of a succession of surface layers; the original stress in a removed layer of material can be readily estimated from the resulting change of length of the specimen. The length measurements were made by means of a special ball-ended micrometer, all the specimens being 4 to 5 in. long. An attempt was made to eliminate errors due to changes of temperature by allowing each specimen to remain in contact with the measuring stand for 12 hr. immediately prior to measurement.

A few successive reductions in diameter, each reduction being about 0·02 in., were made on specimens of each steel in the conditions as-rolled and after oil- and water-quenching from 850° C. A decrease in length was recorded after each operation, indicating that the original skin stresses were compressive. In the bars as-rolled, these stresses did not exceed 5 tons per sq. in.; in the water-quenched specimens the stresses did not exceed 9 tons per sq. in., and in the oil-quenched specimens 7 tons per sq. in.

The skin stresses found in the above cases were compressive and, even with the quenched specimens, did not appear to be of sufficient magnitude to warrant further investigation.

Internal Stresses in a Case-Hardened Steel.

It was considered that a case-hardened material might reveal higher internal stresses than those found above, and a 5% nickel steel * was selected for examination. Preliminary tests on $\frac{1}{2}$-in. dia. rods showed that compressive stresses of over 10 tons per sq. in. could be obtained.

A number of rotating cantilever fatigue test-pieces, with an

* Composition given in Table IX. of the Appendix.

effective diameter of 0·4 in., were case-hardened by being heated for 3 hr. in a cyanide bath at 950° C., cooled in the bath to 830° C. and oil-quenched, then reheated in the bath to 760° C. and water-quenched.

From two specimens selected at random the parallel portion, about 5 in. long × 0·4 in. in dia., was cut off and examined for internal stresses. The hard case of each, as found from a hardness examination of a polished section, was about 0·04 in. thick, and a reduction in radius of about 0·005 in. was made at each machining operation. The average stress over the case of each specimen was

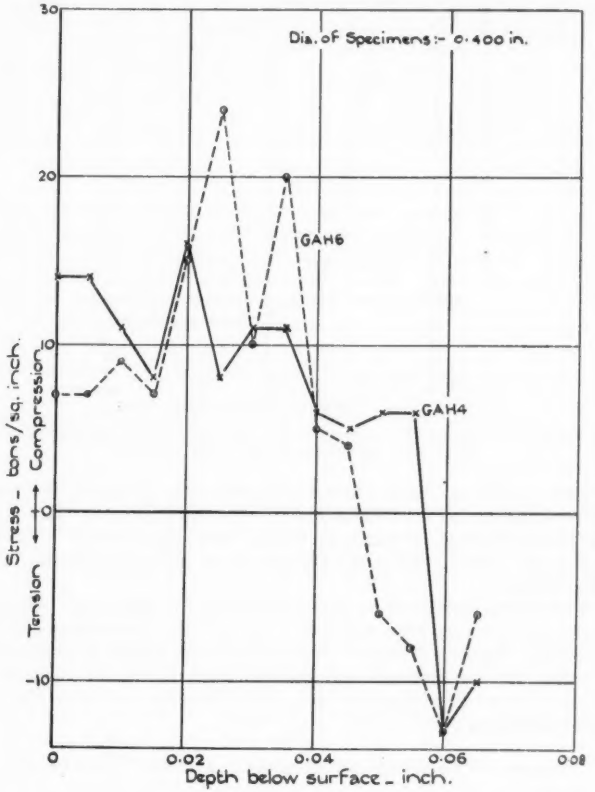


FIG. 1.—Internal Stresses in 5% Nickel Case-Hardened Steel; variation of stress with distance from surface.

about 10 tons per sq. in. in compression, with a maximum of 16 tons in one and 24 tons in the other. The complete results of the internal stress analysis are given in the Appendix, Table VI., and are also plotted in Fig. 1. The variation of hardness over the section of one specimen is given in Fig. 2.

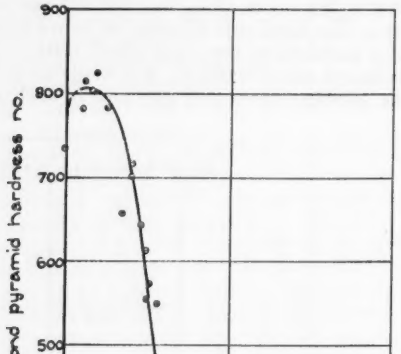


FIG. 2.—Variation of Hardness across the Section of Case-Hardened Specimen. Specimen *GAH5*; dia. 0·400 in.

The remaining specimens were very lightly polished and tested in a rotating cantilever fatigue machine running at about 2100 r.p.m. The limiting range of stress in fatigue was found to be $\pm$ 55 tons per sq. in.; the detailed results are given in the Appendix, Table VII., Series 1.

This value appeared to be satisfactory for specimens where no special precautions were taken to remove circumferential polishing scratches. Since a stress-relieving treatment would possibly entail softening of the material, no attempt was made to compare the fatigue properties of stressed and unstressed specimens in the dead hard condition.

STRESSES PRODUCED ON QUENCHING AFTER TEMPERING.

The foregoing experiments indicated the presence of surface compressive stresses in all the quenched specimens examined. None of these specimens had been tempered, and it was assumed

that tempering, even at a low temperature, would tend to relieve the stresses set up during quenching. Internal stresses in normally hardened and tempered steels would therefore be of small magnitude, and might be expected to exercise a negligible influence on the fatigue properties of such materials. It will be seen, however, that the not uncommon practice of quenching from the tempering temperature may reintroduce stresses, and this has been demonstrated by Buchholtz and Bühler.[9] This matter has been investigated, particularly in regard to the possibility referred to later of improving the fatigue properties of heat-treated spring steels by what has been termed "temper-stressing."

In order to obtain an idea of the stresses produced by quenching from the tempering temperature, a simple comparative method was used.

Machined specimens of chromium-vanadium steel * (6 × 1·25 × 0·34 in.) were heated in a cyanide salt bath at 850° C. for a few minutes and quenched in oil. The specimens were then tempered in a nitrate bath at 600° C. and cooled in air. At this stage the specimens showed no warping and were assumed to be more or less free from stress. They were clamped together in pairs by means of three clamps, as shown in Fig. 4 (Plate XXXIX.), and were then reheated in the tempering bath to the desired temperature and quenched in water. By this procedure, one side of each specimen comes in contact with the water and is rapidly cooled, whilst the other side, in contact with the second specimen, is cooled much more slowly, at a rate corresponding with that of the interior of a specimen of double the above thickness. As in hardening from above the critical temperature, the outer layers of metal yield in tension during the quench from the tempering temperature, and this in turn causes compression stresses to be developed in the outer layers as the inner metal subsequently contracts in cooling to room temperature. Under these conditions the paired specimens bow apart when the clamps are removed, as may be seen in Fig. 4. The curvature assumed may be measured and used to estimate the stresses which are present in the outer layers when the specimens are held together by the clamps. It will be recognised that these stresses should be equivalent to those developed in a specimen of double thickness quenched from the same temperature. The results are given in Table I. and plotted in Fig. 3.

In estimating the stresses, it was assumed that the observed curvature was circular, and that the stress gradient from one side of each specimen to the other was constant; no account was taken of any transverse stress. From a detailed stress analysis carried out later, it appears that most of the compression is concentrated near the surface in contact with the quenching medium, so that the maximum surface stresses shown in Table I. are likely to be lower than the actual values.

* Composition given in Table IX. of the Appendix.

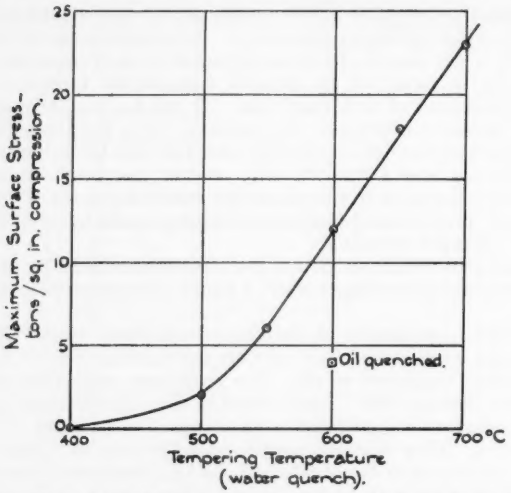


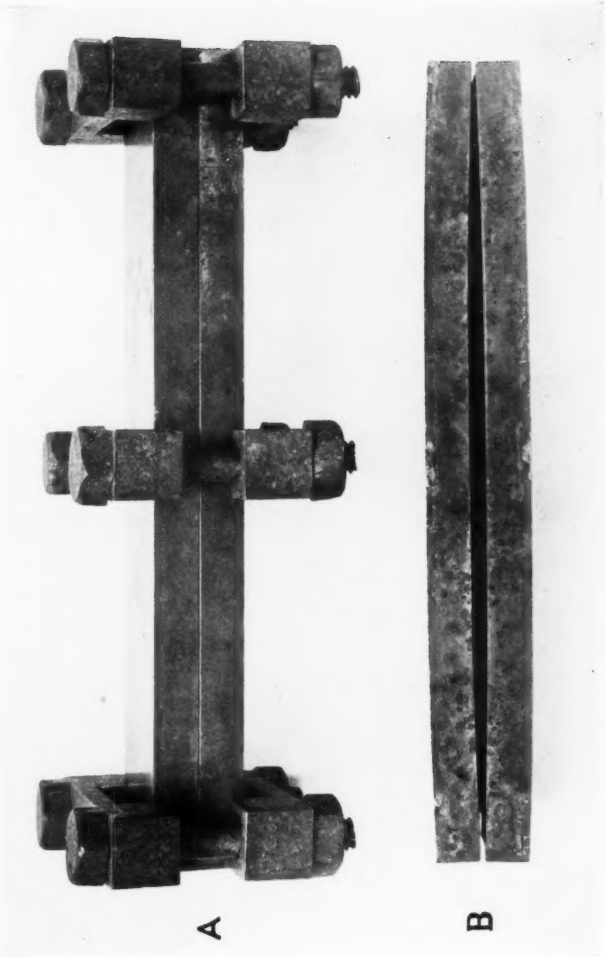
FIG. 3.—Variation of Maximum Surface Stress, in clamped specimen, with tempering temperature.

TABLE I.—*Variation of Stress with Quenching Temperature (Clamped Specimens).*

Material: Chromium-vanadium steel.
Heat Treatment: 850° C. (cyanide), O.Q.; T. 600° C. (nitrates), A.C.; temper-stressed as in Table.

Temper-Stressing Treatment.	Estimated Maximum Surface Stress (Compression). Tons per sq. in.
400° C., W.Q.	0
500° C., W.Q.	2
550° C., W.Q.	6
600° C., W.Q.	12
600° C., W.Q. (four times)	12
600° C., O.Q.	4
650° C., W.Q.	18
700° C., W.Q.	23

The results show that quenching from tempering temperatures below 500° C. produces very little internal stress, but that as the quenching temperature is raised the stress is rapidly increased. It should be noted that some quenchings were carried out from temperatures in excess of the normal tempering temperature for chromium-vanadium steel (600° C.) and the hardness, intrinsic fatigue strength, &c., of the most highly stressed specimens would therefore be expected to be somewhat lower than those of the normally treated material.



(*A*) Plates in clamps before temper-stressing. (*B*) Temper-stressed plates after removal of clamps.

FIG. 4.—Method of Clamping Plates.

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[*To face p.* 432 P.

THE EFFECT OF TEMPER-STRESSING ON FATIGUE STRENGTH.

In a paper by Hankins, Becker, and Mills [3] it is shown that the recarburisation of rolled spring plates before heat treatment sometimes increases their fatigue resistance, which, however, still remains well below that of machined and polished specimens, on account of the local stress concentration caused by surface irregularities. It was suggested, therefore, that the excessive concentration of tensile stress at the root of such irregularities might be reduced by imposing an initial compressive stress on the extreme surface of heat-treated plates. Compressive surface stresses must be accompanied by tensile stresses some distance below the surface, but it was argued that the full intrinsic fatigue resistance available below the surface would more than cover such additional tensile stresses, and that the material would thus withstand higher bending stresses than could safely have been used if the concentration of stress due to surface irregularities had not been reduced by the imposition of the initial surface compression.

When the present work was begun, the authors were unaware of the work of Bühler and Buchholtz [10] which has subsequently been published. These authors have shown that residual compressive stresses near the surface of round machined steel specimens quenched from 600° C. may increase their bending fatigue strength by as much as 20%. In the present investigation, a small increase in fatigue strength has been observed in similar tests on round machined specimens, but further tests on spring plates with rolled surfaces, which normally have lower fatigue resistance, have shown that the effect of compressive stresses, either with or without recarburisation, is much more marked.

(*a*) *Round Specimens—Machined Surfaces.*—Rotating cantilever fatigue tests were carried out on chromium-vanadium steel using un-notched and notched specimens in the unstressed and temper-stressed conditions. Large specimens 0·4 in. in dia. were used, as in the tests on the 5% nickel case-hardening steel, a semicircular groove ($\frac{1}{9}$ mm. radius) being turned in specimens required to show the effect of a notch. All the specimens were heated to 850° C. for a few minutes in the cyanide bath and oil-quenched. They were then tempered at 700° C. in the nitrate bath and quenched in water or cooled in air, according to whether they were required in the temper-stressed or unstressed condition. The results are given in Table II.

The fatigue limit for unstressed and un-notched specimens (test series 2) is somewhat lower than the value determined previously on smaller specimens,[3] but this may be accounted for by the lower hardness resulting from the higher tempering temperature. The ratio of the fatigue strengths of the un-notched and notched specimens in the unstressed condition (*cf.* test series 2 and 4) is about the same, however, as that found for the smaller, harder and completely polished specimens used previously.[3] The fatigue resistance in the

TABLE II.—*Results of Rotating Cantilever Fatigue Tests.*

Material: Chromium-vanadium steel; machined surfaces.

Test Series No.	Heat Treatment.	Condition.	Endurance Fatigue Limit. Tons per sq. in.
2	850° C. (cyanide), O.Q.; T. 700° C. (nitrates), A.C.	Un-notched; un-stressed.	± 38·2
3	850° C. (cyanide), O.Q.; T. 700° C. (nitrates), W.Q.	Un-notched; temper-stressed.	± 41·4
4	850° C. (cyanide), O.Q.; T. 700° C. (nitrates), A.C.	Notched; unstressed.	± 18·1
5	850° C. (cyanide), O.Q.; T. 700° C. (nitrates), W.Q.	Notched; temper-stressed.	± 20·6

NOTE: Detailed results are given in the Appendix, Table VII.

temper-stressed condition (series 3 and 5) is slightly greater than that in the unstressed condition (series 2 and 4), but the ratio between the values for un-notched and notched specimens remains about the same.

(*b*) *Flat Specimens—Surfaces As-Rolled.*—A further series of tests was then carried out on rolled flat plates ($18 \times 1\frac{1}{4} \times \frac{3}{8}$ in., with an effective length of 6 in. reduced to $\frac{3}{4}$ in. in width) using the plane bending fatigue machine referred to in the accompanying paper.[3] In order to recarburise the surface layers, the specimens were heated for 2 hr. in the cyanide bath at 850° C. before oil-quenching. They were then tempered at 700° C. and air-cooled or water-quenched as in the case of the rotating cantilever specimens referred to above. The diamond pyramid hardness numbers of the core and skin of these recarburised specimens were about 310 and 380 respectively, as compared with 410 and 540 for the oil-quenched material tempered at the usual temperature of 600° C. The results of the fatigue tests are given in Table III.

In the recarburised and unstressed condition, the endurance fatigue limit of specimens tempered at 700° C. (series 9) is about the same as for similar but harder specimens tempered at 600° C. (series 8), but in the temper-stressed condition (series 10) the value is probably little short of the intrinsic fatigue limit for material of this hardness, and is much higher than might have been expected from the results obtained with the grooved rotating specimens referred to above.

A confirmatory series of tests on flat plates was then made using a low-chromium spring steel,* the general properties of which were already known.[11] Specimens required in the recarburised condition were heated for 2 hr. in the cyanide bath and cooled to 800° C. before oil-quenching. The "as-rolled and heat-treated" specimens (series 11) were heated for 1 hr. in a muffle at 800° C.

* Composition given in the Appendix, Table IX.

and oil-quenched, but all other specimens treated in the muffle (series 12, 15, and 16) were heated for a few minutes at 850° C. and cooled to 800° C. for quenching, in order to be more nearly comparable with the cyanide-treated specimens. All the specimens were tempered at 600° C., this giving a uniform core hardness of about 380 diamond pyramid number and a skin hardness of about 220 for the decarburised muffle-treated plates and about 500 for the recarburised cyanide-treated plates.

A few preliminary temper-stress tests on the low-chromium steel, using two plates clamped together as previously described, showed that a compressive stress of roughly 13 tons per sq. in. could be obtained on water-quenching from 600° C. and roughly 27 tons per sq. in. on water-quenching from 700° C. These values agree well with those for the chromium-vanadium steel given in Table I., and this seems to suggest that the temper-stresses induced are primarily dependent upon the temperature of quenching. In the case of the low-chromium steel, however, tempering at 700° C. gave a Brinell hardness of 269, and as this appeared to be too low for springs, a tempering temperature of 600° C. was adopted, as stated above, although the surface stress produced by water-quenching

TABLE III.—*Results of Plane-Bending Fatigue Tests on Unstressed and Temper-Stressed Specimens.*

Test Series No.	Material.	Treatment.	Condition.*	Limiting Safe Range of Stress. Tons per sq. in.
6	Chromium-vanadium steel.	850° C. (muffle), O.Q.; T. 600° C., A.C.	Machined and polished; unstressed.	0–56
7		850° C. (muffle), O.Q.; T. 600° C., A.C.	Unstressed.	0–33
8		850° C. (cyanide), O.Q.; T. 600° C., A.C.	Carburised; unstressed.	0–35
9		850° C. (cyanide), O.Q.; T. 700° C., A.C.	Carburised; unstressed.	0–34
10		850° C. (cyanide), O.Q.; T. 700° C., W.Q.	Carburised; temper-stressed.	About 0–45
11	Low-chromium steel.	800° C. (muffle), O.Q.; T. 600° C., A.C.	Unstressed.	0–25
12		850–800° C. (muffle), O.Q.; T. 600° C., W.Q.	Temper-stressed.	0–34
13		850–800° C. (cyanide), O.Q.; T. 600° C., A.C.	Carburised; unstressed.	0–33
14		850–800° C. (cyanide), O.Q.; T. 600° C., W.Q.	Carburised; temper-stressed.	0–41

* The surfaces of the specimens were as-rolled except in series 6.

NOTE: Detailed results are given in the Appendix, Table X.

from this temperature is not so high as might be desired. This is confirmed by the results of the subsequent stress analysis, from which it is seen that the actual surface compressive stress is much greater for the chromium-vanadium steel temper-stressed from 700° C. than for the low-chromium steel temper-stressed from 600° C.

The results of the fatigue tests on the low-chromium steel are included in Table III. The endurance limit shown by the "as-rolled and heat-treated" plates (series 11) is much lower than that of the chromium-vanadium steel in a similar condition (series 7 and 9), probably on account of the more pronounced surface irregularities and surface softness due to decarburisation. On the other hand, either recarburisation or temper-stressing alone (series 13 or 12) exert a marked improvement in the endurance limit, whilst, as in the case of the chromium-vanadium steel, a much higher value is obtained when both recarburising and temper-stressing are applied (series 14).

Estimation of Stresses in Temper-Stressed Plates.

In order to verify the existence and determine the magnitude of internal stresses in the temper-stressed rolled plates used for the fatigue tests, one specimen of chromium-vanadium steel and one of the low-chromium steel (each $18 \times 1\frac{1}{4} \times \frac{3}{8}$ in.) were given the recarburising, quenching, and temper-stressing heat treatment

Table IV.—*Surface Stresses in Steel Plates.*

Material.	Treatment.	Condition.	Thickness of Removed Layer. In.	Estimated Stress in Removed Layer. Tons per sq. in.
Chromium-vanadium steel.	850° C. (cyanide), O.Q.; T. (nitrates) 700° C., A.C.	Carburised; unstressed.	0·011	+ 5
			0·020	− 2
			0·019	0
	850° C. (cyanide), O.Q.; T. (nitrates) 700° C., W.Q.	Carburised; temper-stressed.	0·007	+ 37
			$0{\cdot}009_5$	− 3
			0·011	+ 1
			0·021	+ 4
			0·027	+ 2
Low-chromium-steel.	850–800° C. (cyanide), O.Q.; T. (nitrates) 600° C., A.C.	Carburised; unstressed.	...	... *
			0·010	+ 1
	850–800° C. (cyanide), O.Q.; T. (nitrates) 600° C., W.Q.	Carburised; temper-stressed.	0·007	+ 15
			0·011	+ 3
			0·013	+ 4
			0·021	+ 2

+ indicates compressive stress; − indicates tensile stress.

* The stress in the first layer removed was not measured, but the resulting curvature of the plate was small.

described previously, and one specimen of each steel was similarly treated without being quenched from the tempering temperature.

A succession of thin layers was carefully ground from one face of each specimen, and the resulting curvature due to each machining operation estimated from the deflection on a span of 17 in. This method is similar to that used by Stäblein.[12] During each measurement the specimen was supported on balls at three points, and the deflection measurements were made to an accuracy of about 0·0005 in. The longitudinal stress in each layer removed was computed from the usual bending formulæ; no account was taken of transverse stress, and the estimated longitudinal stress was assumed to be constant over the whole of the removed layer. The results of the stress analyses are given in Table IV., from which it is seen that a high compressive stress was present in the first removed layer of the temper-stressed specimens, and that the specimens not quenched from the tempering temperature were comparatively free from internal skin stress.

As only one temper-stressed specimen of each type of steel was examined for internal stress, it is considered that the results should be regarded only as a general indication of the magnitude of the stresses which may be present in similarly treated material.

The Effect of Stresses Induced by "Scragging."

The investigation, so far, has dealt with the effect of stresses induced by thermal treatment. It is common commercial practice to "scrag" laminated springs before putting them into service. This operation consists in deliberately overloading a spring, and causes a permanent deflection; in service, the spring is loaded in the same direction as in the scragging operation. One effect of this overloading is to distort permanently the outer fibres only of each plate. On removal of the load partial recovery occurs; the inner fibres of the plate, not having been loaded beyond the elastic range, tend towards complete recovery, and a condition of equilibrium is reached such that the outer fibres are in a state of stress. These residual stresses are compressive in the tension side of each plate and tensile in the compression side; their intensities are not readily calculable, and an involved empirical treatment was considered to be outside the scope of this investigation. From the work previously described it was anticipated that these compressive stresses in the tension sides of the plates would prove beneficial to the fatigue properties. Tests were therefore carried out, the low-chromium steel being selected for the purpose.

Plates of the usual dimensions were heat-treated as described above, and were then carefully scragged by being subjected to four-point loading in a testing machine until a permanent deflection of about 0·05 in. on a span of 4 in. was obtained for each specimen. Details of these operations are given in the Appendix, Table VIII. Plane-bending fatigue tests were then carried out on these speci-

mens, the direction of loading during test being the same as that in the scragging operation. The results of these tests are compared in Table V. with those obtained for the same material in the unscragged condition; a definite increase of fatigue resistance was noted (series 11 and 15).

Other and similar tests were carried out on specimens which had first been temper-stressed by the method previously described, and then scragged to the same degree as those above. A still further increase in fatigue resistance was recorded (series 16).

It was not found possible to scrag specimens of low-chromium steel plates which had been subjected to a carburising heat treatment, as fracture occurred before an appreciable permanent deflection could be obtained.

TABLE V.—*Summary of Results of Scragging Tests.*

Material : Low-chromium steel. Surfaces : As-rolled.

Test Series No.	Treatment.	Condition.	Limiting Safe Range of Stress. Tons per sq. in.
11	800° C. (muffle), O.Q.; T. 600° C. (nitrates), A.C.	As-rolled; unstressed.	0–25
15	850–800° C. (muffle), O.Q.; T. 600° C. (nitrates), A.C.; scragged.	As-rolled; unstressed; scragged.	About 0–33
16	850–800° C. (muffle), O.Q.; T. 600° C. (nitrates), W.Q.; scragged.	As-rolled; temper-stressed; scragged.	0–36

NOTE : Detailed results are given in the Appendix, Table X.

CONCLUSIONS.

The preliminary part of the investigation showed that $1\frac{1}{8}$-in. dia. bars of chromium-vanadium and low-chromium steels revealed stresses of not more than 5 tons per sq. in. compression near the surface when in the as-rolled condition, and not more than 9 tons per sq. in. in the dead-hard condition after quenching. Similar measurements on a 5% nickel steel, case-hardened without tempering, showed a maximum internal stress of 24 tons per sq. in. somewhat below the surface.

It has been demonstrated that high compressive stresses may be induced near the surfaces of a hardened spring steel plate by quenching in water from a suitable tempering temperature, and that such treatment definitely increases the fatigue resistance of the unmachined material. The increased fatigue resistance is considered to be due mainly to the action of residual compressive stresses in reducing the concentration of tensile stress at the roots of surface irregularities on the tension sides of the plates. The fatigue resistance of rolled specimens in the cyanide, recarburised condition is generally higher than that of similar specimens in the

ordinary muffle-treated condition,[3] but temper-stressing markedly improves the fatigue resistance of the materials in either condition.

It will be noted that the specimens of low-chromium steel were quenched from a lower tempering temperature than those of chromium-vanadium steel, and the stress analysis shows the former to contain much lower surface compressive stresses than the latter. As temper-stressing brought about a marked improvement in fatigue resistance of the low-chromium steel, it is concluded that in order to obtain such improvement very high internal compressive stresses are not essential.

The few tests made on scragged spring steel plates suggest that the fatigue resistance of such plates is increased by the scragging operation. This is likely to be due to the beneficial effects of residual compressive stresses near the tension surfaces of the plates.

All the internal stresses considered during the investigation have proved to be compressive near the surface (compensating tensile stresses naturally occurring within the material), probably with the single exception of those in the compression side of a scragged plate. Accordingly, the effect on the fatigue resistance of a tensile stress in the tension surface of a spring plate subjected to bending has not been studied, but it is suggested that it would be adverse.

Acknowledgments.

The work described has been carried out as an item of research financed by the Department of Scientific and Industrial Research and supervised by the Executive Committee of the National Physical Laboratory, to whom the authors are indebted for permission to publish the results.

The authors desire to acknowledge the help and encouragement given by Dr. C. H. Desch, F.R.S. (Superintendent, Metallurgy Department), Dr. H. J. Gough, F.R.S. (Superintendent, Engineering Department), and Dr. G. A. Hankins (Engineering Department) and the assistance of Mr. H. R. Mills, B.Sc., and Mr. R. H. Spencer.

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(3) Hankins, Becker, and Mills: "Further experiments on the effect of surface conditions on the fatigue resistance of steels." This Journal, p. 399 P.

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(6) Heyn: "Internal strains in cold wrought metals, and some troubles caused thereby." *Journal of the Institute of Metals*, 1914, No. 2, p. 3.

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(10) BÜHLER and BUCHHOLTZ: "The effect of internal stresses on the bending fatigue strength." *Stahl und Eisen*, 1933, vol. 53, p. 1330.
(11) HANKINS and FORD: "The mechanical and metallurgical properties of spring steels as revealed by laboratory tests." *Journal of the Iron and Steel Institute*, 1929, No. I., p. 217.
(12) STÄBLEIN: "Stress measurements on bars quenched on one side." *Kruppsche Monatshefte*, 1931, vol. 12, p. 93.

APPENDIX.

TABLE VI.—*Internal Stresses in Case-Hardened Specimens of 5% Nickel Case-Hardening Steel.*

Specimen.	Heat Treatment.	Diameter of Specimen. In.	Total Decrease in Length. In.	Estimated Stress in Removed Layer. Tons per sq. in.
GAH4	950–830° C. (cyanide), O.Q.; 760° C. (cyanide), W.Q.	0·4010	...	...
		0·3909	$0{\cdot}0002_3$	+ 14
		0·3802	$0{\cdot}0004_4$	+ 11
		0·3703	$0{\cdot}0005_3$	+ 7
		0·3602	$0{\cdot}0008_4$	+ 16
		0·3505	$0{\cdot}0010_7$	+ 7
		0·3397	$0{\cdot}0013_6$	+ 11
		0·3300	$0{\cdot}0016_4$	+ 11
		0·3200	$0{\cdot}0018_6$	+ 6
		0·3102	$0{\cdot}0020_8$	+ 5
		0·3000	$0{\cdot}0023_5$	+ 6
		0·2903	$0{\cdot}0026_4$	+ 6
		0·2803	$0{\cdot}0025_3$	− 13
		0·2700	$0{\cdot}0024_9$	− 10
GAH6	950–830° C. (cyanide), O.Q.; 760° C. (cyanide), W.Q.	0·4001	...	...
		0·3909	$0{\cdot}0001_1$	+ 7
		0·3804	$0{\cdot}0002_3$	+ 9
		0·3700	$0{\cdot}0004_4$	+ 7
		0·3604	$0{\cdot}0007_3$	+ 15
		0·3505	$0{\cdot}0011_9$	+ 24
		0·3401	$0{\cdot}0014_7$	+ 10
		0·3298	$0{\cdot}0019_6$	+ 20
		0·3198	$0{\cdot}0021_9$	+ 5
		0·3100	$0{\cdot}0024_2$	+ 4
		0·2998	$0{\cdot}0024_5$	− 6
		0·2893	$0{\cdot}0024_1$	− 8
		0·2803	$0{\cdot}0023_3$	− 13
		0·2701	$0{\cdot}0023_7$	− 6

+ indicates compressive stress. − indicates tensile stress.

TABLE VII.—*Results of Rotating Cantilever Fatigue Tests.*

Test Series No.	Material.	Treatment.	Condition.	Specimen No.	Stress. Tons per sq. in.	No. of Reversals (Millions).	Endurance Fatigue Limit. Tons per sq. in.
1	5% nickel case-hardening steel.	950° C. (cyanide), cooled to 830° C., O.Q.; 760° C. (cyanide), W.Q. (not tempered).	Case-hardened and temper-stressed.	*GFU4*	±58·5	3·11 B	±55·0
				GFU6	±56·5	3·53 B	
				GFU4	±53·2	11·0 U	
				GFU5	±50·0	10·2 U	
				GFU1	±44·6	10·0 U	
2	Chromium-vanadium steel.	850° C. (cyanide), O.Q.; T. 700° C. (nitrates), A.C.	Un-notched; unstressed.	*S5C5*	±41·0	0·21 B	±38·2
				S5C1	±40·0	0·19 B	
				S5C8	±38·3	3·6 B	
				S5C6	±36·8	11·1 U	
3		850° C. (cyanide), O.Q.; T. 700° C. (nitrates), W.Q.	Un-notched; temper-stressed.	*S5C7*	±45·4	1·01 B	±41·4
				S5C3	±43·5	0·4 B	
				S5C2	±42·5	0·7 B	
				S5C4	±41·6	2·2 B	
				S5C3	±41·3	11·2 U	
4	Chromium-vanadium steel.	850° C. (cyanide), O.Q.; T. 700° C. (nitrates), A.C.	Notched; unstressed.	*S5A1*	±19·9	0·12 B	±18·1 *
				S5A6	±18·3	0·40 B	
				S5A8	±18·1	12·0 U	
				S5A2	±17·7	10·5 U	
5		850° C. (cyanide), O.Q.; T. 700° C. (nitrates), W.Q.	Notched; temper-stressed.	*S5A4*	±21·0	0·36 B	±20·6 *
				S5A7	±20·8	0·75 B	
				S5A5	±20·8	0·24 B	
				S5A4	±20·6	18·0 U	
				S5A3	±20·5	11·0 U	

U = Unbroken. B = Broken.

* Calculated on the diameter at bottom of notch.

TABLE VIII.—*Details of Scragging Operations.*

Dimensions of test-pieces : 18 × 1¼ × ⅜ in.
Supporting span : 17 in.
Loading span : 10 in.
Material : Low-chromium steel, surfaces as-rolled.

Heat Treatment.	Condition.	Specimen.	Total Load. Tons.	Permanent Set on 4-in. Span. In.
850–800° C. (muffle), O.Q.; T. 600° C. (nitrates), A.C.	Unstressed.	*S3U24*	1·28	0·045
		S3U23	1·25	0·055
850–800° C. (muffle), O.Q.; T. 600° C. (nitrates), W.Q.	Temper-stressed.	*S3U17*	1·4	0·046
		S3U15	1·4	0·047
		S3U16	1·45	0·046
		S3U18	1·45	0·046

TABLE IX.—*Composition of Materials Used.*

Material.	C. %.	Si. %.	Mn. %.	S. %.	P. %.	Ni. %.	Cr. %.	V. %.
5% nickel steel (nominal) . .	0·07	0·06	0·18	0·02	0·01	5	...	...
Chromium-vanadium steel . . .	0·55	0·29	0·68	Trace	0·01	0·12	1·16	0·27
Low-chromium steel.	0·60	0·26	0·62	0·036	0·036	...	0·56	...
Silico-manganese steel . . .	0·54	1·95	0·94	0·02	0·02	...	...	...
0·6% carbon steel .	0·60	0·22	0·77	0·007	0·012	0·08	0·12	...

TABLE X.—*Results of Plane-Bending Fatigue Tests.*

Test Series No.	Material.	Treatment.	Condition.*	Specimen No.	Stress. Tons per sq. in.	No. of Repetitions (Millions).	Limiting Safe Range of Stress. Tons per sq. in.
6	Chromium-vanadium steel, *S5*.	850° C. (muffle), O.Q.; T. 600° C. (nitrates), A.C.	Machined and polished; unstressed.	*S5L5*	0–60	0·31 B	0–56
				S5L2	0–60	0·40 B	
				S5L3	0–57	0·23 B	
				S5L2	0–55	6·01 U	
7		850° C. (muffle), O.Q.; T. 600° C. (nitrates), A.C.	Unstressed.	*S5H7*	0–40	0·18 B	0–33
				S5H9	0–35	0·23 B	
				S5H10	0–33	1·13 U †	
				S5H8	0–32	4·67 U	
				S5H6	0–26	1·31 U †	
8		850° C. (cyanide), O.Q.; T. 600° C. (nitrates), A.C.	Carburised; unstressed.	*S5AA2*	0–37	0·08 B	0–35
				S5AA6	0–36	1·26 B	
				S5AA4	0–36	6·47 U	
				S5AA4	0–33	6·00 U	
9		850° C. (cyanide), O.Q.; T. 700° C. (nitrates), A.C.	Carburised; unstressed.	*S5AA8*	0–40	0·11 B	0–34
				S5AA9	0–35	0·14 B	
				S5AA10	0–33	6·52 U	
				S5AA12	0–30	6·58 U	
10		850° C. (cyanide), O.Q.; T. 700° C. (nitrates), W.Q.	Carburised; temper-stressed.	*S5AA7*	0–46	6·72 U	About 0–45
				S5AA1	0–45	0·27 B	
				S5AA5	0–44	6·93 U	
				S5AA3	0–42	7·76 U	
				S5AA1	0–40	7·09 U	
11	Low-chromium steel, *S3*.	800° C. (muffle), O.Q.; T. 600° C. (nitrates), A.C.	Unstressed.	*S3U1*	0–30	0·34 B	0–25
				S3U3	0–28	0·38 B	
				S3U4	0–27	0·46 B	
				S3U5	0–26	0·61 B	
				S3U2	0–25	6·08 U	
				S3U6	0–25	7·07 U	
12		850–800° C. (muffle), O.Q.; T. 600° C. (nitrates), W.Q.	Temper-stressed.	*S3U19*	0–38	0·27 B	0–34
				S3U20	0–35	0·79 B	
				S3U22	0–34	6·09 U	
				S3U21	0–33	5·93 U	
13		850–800° C. (cyanide), O.Q.; T. 600° C. (nitrates), A.C.	Carburised; unstressed.	*S3U8*	0–40	0·06 B	0–33
				S3U9	0–36	0·04 B	
				S3U10	0–34	0·18 B	
				S3U8	0–33	7·34 U	
14		850–800° C. (cyanide), O.Q.; T. 600° C. (nitrates), W.Q.	Carburised; temper-stressed.	*S3U11*	0–50	0·05 B	About 0–41
				S3U12	0–43	1·10 B	
				S3U14	0–42	0·21 B	
				S3U11	0–42	6·31 U	
				S3U13	0–41	3·35 U †	
				S3U11	0–35	6·11 U	
15		850–800° C. (muffle), O.Q.; T. 600° C. (nitrates), A.C.	Unstressed; scragged.	*S3U23*	0–35	0·40 B	About 0–33
				S3U24	0–32	6·39 U	
16		850–800° C. (muffle), O.Q.; T. 600° C. (nitrates), W.Q.	Temper-stressed; scragged.	*S3U15*	0–44	0·36 B	0–36
				S3U16	0–40	0·75 B	
				S3U17	0–40	0·98 B	
				S3U18	0–38	0·60 B	
				S3U17	0–35	6·37 U	

* The surfaces of the specimens were as-rolled except in series 6.
† Broke in grips.
U = Unbroken. B = Broken.

[This paper was discussed jointly with the preceding one by Hankins, Becker, and Mills.]

JOINT DISCUSSION.

The papers by Hankins, Becker, and Mills on "Further Experiments on the Effect of Surface Conditions on the Fatigue Resistance of Steels," and by Becker and Phillips on "Internal Stresses and their Effect on the Fatigue Resistance of Spring Steels" were discussed jointly.

Mr. S. A. MAIN (Sheffield) remarked that in the conclusion to Section I. of the paper by Hankins, Becker, and Mills (on the effect of surface conditions) the authors stated: "It is concluded from the foregoing experiments that the combination of surface decarburisation and irregularities of shape is the major cause of the low fatigue resistance of heat-treated unmachined spring steel plates." He thought there had never been any reasonable doubt about that for several years past. It had been demonstrated very forcibly by workers at the National Physical Laboratory and elsewhere that decarburisation was an important factor, and in their own practical experience people had seen cases where fatigue fractures had actually started, beyond any doubt, from surface irregularities. He thought that the authors had not done themselves justice in putting their conclusion on that point in that way, because, of course, they had gone much further than that. They had actually done a difficult thing and determined the extent of each of those two factors.

The point was that steel in practice did not have the resistance to fatigue which it ought to have, because of those two factors, and the course which the authors had pursued had been to try certain methods of curing those two defects; but he thought it should be possible to put a stop to the whole matter by giving a finished surface to the steel after the heat treatment was finished. He thought that was the positive way to go about it. If one adopted an expedient which might appear advantageous with a surface which had many irregularities, the effect of that treatment would surely be much better if applied to a finished surface; or, to put it the other way round, why accept the necessity for applying special treatment? After having in the ordinary course heat-treated the steel and done wrong things to it by decarburisation and perhaps by rolling-in scale in rolling operations, why not remove all that by a final surfacing treatment?

The authors had had to have some means of finding out whether the methods that they were investigating were beneficial or not, and they had adopted the regular fatigue test. That test failed, unfortunately, in certain cases to determine what was the best steel for a spring. It failed, as the authors themselves showed, on very hard steel. With very hard steel—he referred to a hard steel properly prepared, and with a good surface—high fatigue values were obtained, as the authors demonstrated, but such steels were not successful for springs. A year ago he had been much attracted by a paper by Dr. Hankins and Mr. Mills, in which

they applied repeated impact stresses to spring steels, and that test did actually discriminate better, to his mind, for spring purposes than the ordinary fatigue test. It did, in fact, show up the harder steels in an unfavourable light, which corresponded to what was found in practice. He would, therefore, much rather have seen the tests in the present paper carried out with repeated impact stresses.

There was a minor point of nomenclature to which he wished to refer; it was the use of the expression " as-forged." It would be found, he thought, that in most of the papers which came from the industry that expression was used for steel which was really as-forged, *i.e.*, which had had nothing done to it after it had been forged, even by heat treatment. The term in the present paper, however, was applied, and in his experience for the first time, to forged steel which had been subsequently heat-treated. He had been a little confused over that, and he thought other readers might be the same.

Regarding the other paper (by Becker and Phillips), it would interest the authors to know that the effect of temper-stressing to which they referred, and of which they had found such tangible evidence in laboratory tests, had been demonstrated in a practical case. Some shafts which his own firm manufactured regularly were subject a few years ago to an epidemic of failures, and a number of them were sent back with quite beautiful fatigue fractures. These failures were investigated. The shafts were of carbon-manganese steel, and their final treatment was at 600° C. It was found in the investigation that that treatment, instead of being followed, as was normally the case, by quenching in water, had for a period been followed by cooling in air, and there was no doubt that that was the cause of the trouble. There had never been any trouble before that period, and when, having that evidence, in regard to which they were very kindly helped by Dr. Gough, they returned to the original conditions, there was no trouble again. At Dr. Gough's instigation, they demonstrated on those shafts, by somewhat similar methods to those described in the paper, that the stresses in the outer surface did exist and were of much greater magnitude in the water-cooled shafts. The authors could, therefore, take it that the effects of temper-stressing which they pointed out in the paper were real, and could operate favourably in actual practice.

Mr. A. E. Frost (Sheffield) said he appreciated the care which was necessary in the tests undertaken, and realised the thought which must be exercised in arriving at conclusions. He recognised the value and possibilities of the results, and had the will, and, very fortunately, the facilities for applying any results which would appear capable of useful practical application.

Dealing first with the paper by Becker and Phillips, on the

effect of internal stresses on the fatigue resistance of spring steels, the results outlined were important, for, whilst the quenching of spring-leaves in water at the tempering temperature was sometimes specified, the practice was unusual rather than common, and in any case the relative effect of the temperature at which the plates were temper-stressed to the limiting range of stress was, he believed, something new, and would receive attention.

It would appear from the results that, in order to raise the limiting range of stress to a useful value, a sacrifice must be expected in the internal hardness; and this raised a point as to what was the maximum tempering temperature which would maintain the minimum degree of hardness called for in a spring. He would suggest that a maximum temperature for temper-stressing could be arrived at by establishing a minimum internal hardness, as determined by the following test:

> Test specimens to be cambered to a radius 54 times their thickness, deflected to the straight position, following which the permanent loss of camber should not be greater than 5% of the original camber.

In that connection, a further question arose as to whether the effect of bending a heated spring plate would produce any appreciable difference in fatigue results from tests carried out on straight plates, and, furthermore, whether quenching immediately following the bending operation would produce results different from those obtained by bending and allowing to cool, followed by reheating for quenching.

The effects of scragging had been previously brought forward in other investigations, but the results had not been so clearly defined as in the present paper. Whilst it was useful to know the good effects which scragging might have on the limiting range of stress, it might be usefully stated that it was standard British practice to scrag all laminated springs to $L^2/900t$, L being the effective length and t being the plate thickness. Whether an amount of scrag greater or less than this would give better results was a point which the authors might consider it useful to determine in some future programme of work, because, for many reasons, the amount of standard scrag on the complete spring imposed a stress on the individual plates which might vary from 30 to 90 tons per sq. in. The importance of further investigations on the effects of scragging need not be further emphasised.

With regard to the experiments described in the section dealing with internal stress measurements on rolled bars, it was stated that a decrease in length was recorded after each operation, indicating that the original skin stress was compressive. The speaker found some difficulty in following that; he could not quite relate the removal of a compressive strain to the production of a decrease in length as a result. Possibly the authors could give some further explanation on that point.

Turning to the paper by Hankins, Becker, and Mills, on the effect of surface conditions, he would like to ask whether for practical purposes the expression " surface irregularities of shape " could be considered to designate the same problem as oxide penetration, a term used by other investigators of the problem of surface effects on spring steels. The term " surface irregularities of shape " was used frequently in the present paper. An answer to that question would assist springmakers in the practical applications they were now making of the various investigations which had been carried out on surface effects. They would like to know whether the present paper introduced another disability, or whether it was a further contribution to a problem which had already been brought to their notice. There were various expressions in the paper which suggested the question. If the authors considered that for practical purposes " surface irregularities of shape " and " oxide penetration " constituted the same problem, then he was unconvinced that the artificial notches produced bore a practical relation to the as-rolled surface of spring steel.

With regard to the authors' conclusion that " surface recarburisation of decarburised steels can hardly be recommended for general commercial application," the steelmaker would like the authors to be as definite as possible with regard to that conclusion, because of the difference between the plant which he must consider providing for recarburisation and that for machining the surface.

He considered that an important question had been raised in the paper as to whether the method of testing between plus and minus fatigue limits as opposed to zero to plus had any appreciable effect on the results obtained where the specimen to be tested was in the " as-rolled " or the " as-rolled and recarburised " condition. In the paragraph in Section II. of the paper dealing with tests on spring plates machined on one side, it was shown " that the tension side of the specimen is of paramount importance, whilst that of the compression side is comparatively immaterial." It seemed a reasonable deduction, therefore, that when both sides of a specimen, where surface effects were present, were subjected to tension, as in the case of plus and minus reversals, the endurance fatigue limit would be less than when one side only was subjected to tension; moreover, the relation between results obtained from machined and unmachined specimens, as, for example, 46 tons to 11 tons, might be substantially altered had only one side of the specimen been subjected to tension. He would like to know whether in the authors' opinion that difference in the method of test explained the difficulty outlined at the beginning of the conclusion to Section II. (" It is difficult to explain the whole of the fatigue results on the recarburised specimens in a logical manner.")

With regard to Table II. of the paper, he wondered whether it was correct to assume that the " Neglecting Depth of Notch "

column gave the results estimated on the minimum diameter, and the "Corrected for Depth of Notch" column on the maximum diameter of the specimen. He had assumed that that was so, but he would like to be sure on that point.

The information that the springmaker was most in need of at present was to establish the most suitable material to give a test result where an initial stress of 20 tons and a maximum stress of 40 tons were imposed, the type of specimen cambered, the width being approximately eight times the thickness, with the corners well rounded. Next to the testing of complete springs, he considered this to be the most useful form of test. He suspected that round specimens, particularly where surface defects were present, might produce results not relative to flat specimens.

Probably the best way of showing his appreciation to the authors for the great interest they were taking to assist in a possible solution of spring problems was to tell them that some of their previous findings had been applied in commercial form, that many springs so produced were in service, and that the results so far would indicate a distinct improvement in the life and functioning of a laminated spring. The object of this statement was to thank them for services rendered, to encourage them to produce still further results, and to indicate what he believed to be a most useful avenue for further research work on the spring problem.

Mr. V. D. Pavord (Leicester) said that he wished to give his experience of springs and springmakers, and members must not be surprised if his remarks were a little different from those of the previous speakers.

Some four or five years ago his firm used very considerably what was known as "patented wire" for the manufacture of springs, and they had so much trouble with springs that he decided to go into the whole matter.

It was found that the best remedy for the defect of breaking springs was to obtain the right kind of wire for the duty that the spring had to do. They now used four different kinds of wire, and only one was heat-treated by themselves or the makers. The others were generally drawn to a certain tensile strength. In some cases it was necessary to use wire made from a pure Swedish base.

Unquestionably both papers were most interesting, and he agreed that fractures did start from the decarburised surface, but if that surface were removed, fractures would be less likely to occur, provided the spring was properly designed for the work it had to do.

Not many years ago their silver steels came in with a decarburised surface, which caused inconvenience after the hardening operation, by leaving a soft surface, and so he said to the manu-

facturers, " Why not remove the decarburised surface by grinding when possible, prior to the last drawing operation ? "

The steelmakers of Sheffield apparently at that time were not aware that they drew down to the finished size, and left the decarburised surface on the actual wire sent out to the customer, which was not a fair proposition. To overcome the whole trouble, the decarburised surface was removed at a suitable stage before reaching the finished size.

CORRESPONDENCE.

Mr. H. SUTTON (Farnborough), with reference to the paper by Hankins, Becker, and Mills, wrote that the authors' results were of great practical interest, and were of importance in connection with the problem of producing springs for high performance.

The importance of avoiding decarburisation was clearly indicated by the results of their carefully conducted experiments. It would be particularly interesting to have the authors' remarks on the subject of penetration of oxygen on samples heat-treated by them without precautions against scaling. He raised that point because the authors had probably examined their samples for detection of oxygen penetration on the lines mentioned, recently described by Riddihough and de Belin,[1] and might be able in that way to assist materially the work of those who had occasionally to examine springs which had failed, to discover the cause of failure. There was already a considerable amount of suspicion centred round the matter of oxygen penetration, and a recent publication by Schottky and Hiltenkamp [2] suggested that atmospheric nitrogen might be taken up by steels under conditions causing rubbing, *e.g.*, between the leaves of springs. These investigators found that nitride formation occurred at grain boundaries, thereby facilitating breakdown under working stresses in the affected areas. It would be of interest to know whether the authors had observed anything of this kind. The fact that nitrogen might be introduced during treatment in cyanide baths might have some bearing on the apparent failure of cyanide-bath heat treatment to develop the maximum fatigue properties of the authors' spring materials. The metallurgical side of the problem seemed to demand examination of the surface layers of the various materials in the different conditions, for content of carbon, oxygen and nitrogen—admittedly a task of considerable magnitude.

Mr. L. W. SCHUSTER (Manchester), referring to the paper by Hankins, Becker, and Mills, wrote that in Section II. of the paper the remarks on tests on spring plates machined on one side

[1] *Journal of the Iron and Steel Institute*, 1931, No. II., pp. 445–447.
[2] *Stahl und Eisen*, 1936, vol. 56, pp. 444–446.

FIG. A.—Failure in Eccentric Shaft of Stone Crusher subjected to repeated uni-directional bending. Creeping fracture originated on the compression side. (*See* Schuster's correspondence.)

[*Hankins, Becker, and Mills, correspondence.*

[*To face p.* 418 P.

gave the impression that any specimen when tested in the plane-bending fatigue machine was likely to fail at the tension side. He would like to ask the authors if that was intended, or applied only to the particular steels tested. In a series of failures that the writer had experienced of the eccentric shaft of a stone crusher, which was subjected merely to stress from repeated uni-directional bending, the creeping fracture had always originated at the compression side, an example being given in the photograph, Fig. A (Plate XXXIX A). The material was mild steel containing about 0·40% of carbon. This difference in behaviour was therefore a point for explanation. The writer noticed that the authors' specimens were tempered at 500° C., but in the description it was not stated whether they were afterwards quenched or air-cooled. Becker and Phillips showed that, even if a quenching treatment was carried out at 500° C., the resulting stress was inconsiderable; if, therefore, the presence of initial stress was not the cause of the discrepancy, the writer would be interested if an alternative explanation were offered.

With reference to the paper by Becker and Phillips, Mr. Schuster stated that in regard to the increase in fatigue range experienced when the surface of the specimen carried a compressive stress, he would like to ask the authors whether the conclusion was intended to apply only when a uni-directional repeated stress was applied. He had understood that previous experiments showed that, when equal alternating stresses were applied, the tendency was for the internal stresses gradually to neutralise one another, and therefore for the fatigue value to remain unaltered.

AUTHORS' REPLIES.

Messrs. HANKINS, BECKER, and MILLS wrote in reply to the discussion on their paper that they were glad that Mr. Main agreed with them that the combination of surface decarburisation with surface irregularities of shape was the major cause of the low fatigue resistance of unmachined spring steels, and they now hoped that as a result of the work recorded in Section I. of the paper this conclusion would be accepted generally. They did not agree with Mr. Main, however, that it was now wise to put a stop to the whole matter by machining and polishing as the final operation after heat treatment. Final machining was not practicable or even possible in many cases, and they were of the opinion that there was still a wide field of investigation in regard to the effect of surface conditions on fatigue resistance which would repay detailed investigation by steel manufacturers and users.

The use of the term "as-forged" in describing specimens which had been subsequently heat-treated had been criticised by Mr.

Main, and on re-reading some passages the authors agreed that, in certain instances, this might lead to some confusion. They had wished to differentiate concisely between two types of surface—" the surface as forged " and " the surface as machined "—and it was perhaps not obvious that in both instances the material itself might be in the forged condition. Such a statement as " the surfaces are in the as-forged, heat-treated condition " was intended to imply that the material had been forged and heat-treated, and that no surface machining had been given either before or after heat treatment. The statement " the surfaces are in the unmachined, heat-treated condition " might be preferable, but did not seem to the authors to be so comprehensive and left some doubt as to whether specimens might have been machined before heat treatment.

They were particularly pleased to receive Mr. Frost's interesting remarks and his assurance that the work was being found directly useful when applied to practical spring problems; the primary object of the work was, of course, to assist the industry concerned.

In regard to the interpretation of " surface irregularities of shape," the authors included under that heading any definite irregularities which would produce marked stress concentrations under external load. Thus, pits at the surface or small holes just below the surface, whether filled with oxide or not, were regarded as irregularities of shape. A solid solution of oxide in iron, as postulated by Riddihough and De Belin would not, of course, be regarded as an irregularity of shape. The authors regretted that they could not be any more definite in regard to the possible advantages of recarburising. It was not easy to give a definite reply to Mr. Frost on the questions he had raised on the validity of testing under reversed stresses (zero mean stress) as against the repeated stresses (mean stress equal to half the range of stress). In general, throughout the whole of the present work, the rotating bending test applying reversed stresses had been used to investigate the underlying principles and for preliminary explorations, this form of test being much more quickly and conveniently carried out than the plane bending test applying repeated stresses. The plane bending test was then used to check the more important points under conditions approximating to practical spring usage and to obtain quantitative values which might be useful in spring design.

Mr. Frost mentioned certain stress figures on a cambered spring, *viz.*, 20 tons per sq. in. initial stress and maximum stress of 40 tons per sq. in. In the opinion of the authors, failure under this stress range, if it occurred, would almost certainly start in the tension side of the spring, and the initial camber would have little effect. With regard to Table II., the stresses given in the column headed " corrected for depth of notch " were calculated from the diameter of the test-piece at the bottom of the notch. The difficulty in explaining the results obtained on the recarburised specimens did

not arise from any discrepancy between the two forms of test; the results given in Table IV. were only regarded as arising from preliminary experiments, and any general quantitative conclusions in regard to recarburising should be based on the results given in Tables V. and VI.

The authors, agreed, of course, with Mr. Pavord that in the manufacture of spring wires it was sound practice to remove the decarburised surface by grinding at a convenient stage during manufacture.

Mr. Sutton raised an interesting question as to the penetration of oxygen during heat treatment and its possible effect upon fatigue resistance. Where the oxidised surface penetrated the metal irregularly there could be no doubt that the fatigue resistance was lowered. This was particularly noticeable with the high-tensile forgings. Although the authors believed oxygen in solid solution was present in the decarburised zone, they were not convinced that the apparently unusual grain boundaries referred to by Riddihough and De Belin, and sometimes noticed in the decarburised zone, had any direct connection with the presence of such oxygen. Whether or not the presence of oxygen in solid solution was to be seen in this way, the effect upon fatigue did not appear to be important in the steels examined, where the softness of the decarburised surface appeared to be quite sufficient to account for the lowering of the fatigue resistance. In the tests described in the present paper no rubbing on the surface had occurred, and it was therefore improbable that any atmospheric nitrogen had entered in the manner recently described by Schottky and Hiltenkamp. On the other hand, it was certain that nitrogen was introduced during heat treatment in the cyanide bath, but this seemed to have a slightly beneficial rather than a deleterious effect upon the fatigue properties, as had been shown previously [1] for specimens heat-treated in cyanide after machining. It seemed, therefore, that the failure of cyanide-bath heat treatment to develop the intrinsic maximum fatigue properties of unmachined spring material could not be ascribed to any deleterious effects of nitrogen, but rather to the presence of irregularities and inclusions in the rolled surface.

In reply to Mr. Schuster on the question of failures on the tension side of the plate in the plane bending machine, the vast majority of tests in that machine had been made with spring steels, in all of which the cracks appeared to start on the tension side, irrespective of whether the surfaces were machined or unmachined, recarburised or temper-stressed. It was not possible to be definite in regard to other steels, but, as an expression of opinion by the authors, failure in a mild steel would also be likely to start on the tension side. Accordingly, they could offer no explanation of the failures which Mr. Schuster found to start on the compression side of the shaft. The fracture was a little suggestive of torsional

[1] *Journal of the Iron and Steel Institute*, 1931, No. II., p. 419.

stresses, but presumably Mr. Schuster was satisfied that such stresses were not of sufficient magnitude to affect the problem.

In reply to the discussion on the paper describing the effects of internal stresses, Messrs. BECKER and PHILLIPS wrote that they were interested to hear of Mr. Main's experience in regard to the value of temper-stressing in improving the fatigue resistance of shafts.

Mr. Frost made a valuable suggestion as to the test, which should be applied in determining the lowest internal hardness which was permissible in a spring. For some materials, particularly carbon steels, the lowest permissible hardness might be obtained before a tempering temperature sufficiently high to give adequate stressing had been reached. There was reason to believe that appreciable improvement might be obtained on temper-stressing from temperatures below 600° C., although no such tests had been made. The effect of the mass of the plate or bar would be of importance in determining the compressive stress which could be induced near the surface by quenching, and this factor might also operate favourably and enable improvements to be effected by temper-stressing from the lower temperatures.

As far as the authors were aware, the fatigue characteristics of bent plates were the same as those of straight plates. Any stresses which might be induced during bending would be automatically relieved if the bending were carried out whilst the plate was hot or if the plate were subsequently heated to a sufficiently high temperature. They were glad that Mr. Frost had emphasised the importance of further investigations on the effects of scragging. This subject had only been touched upon in the paper, but the results obtained showed clearly that the scragging of springs was likely to have a beneficial effect upon their fatigue resistance if carried out with due regard to the factors involved.

With regard to the measurements of internal stress, if removal of an outer layer caused a decrease in length of the remainder of the bar, that decrease must have been caused by original internal stresses which had become unbalanced. Those stresses in the remainder of the bar must have been tensile stresses, and for equilibrium in the original bar those in the removed layer must have been compressive.

In reply to Mr. Schuster, the authors concluded that initial surface compressive stress was beneficial in steel subjected to either alternating or repeated stresses. Both in Table II. (alternating stress) and Table III. (repeated stress) specimens with surface compressive stress showed a definite increase in fatigue resistance, although the increase shown in Table II. was not so great as that in Table III. This difference, however, was not primarily attributed to the method of stressing, but rather to the fact that the alternating stress test-pieces had machined surfaces, and therefore gave relatively high fatigue resistance even in the unstressed condition.

The experiments of Bühler and Buchholtz [1] had shown that for a 0·57% carbon steel in the machined condition, the internal stresses introduced by quenching from the tempering temperature tended to be relieved during the fatigue test. Thus, the beneficial effects due to the internal stresses were lost to a certain extent as the test proceeded. This, however, did not appear to occur in the present investigation, the reason probably being that the fatigue resistance of the unmachined plates, although considerably improved by temper-stressing, was still below the intrinsic endurance limit for the material. The stresses imposed during the tests would, therefore, be insufficient to reduce the internal stresses to the same extent as occurred in the case of the machined test-pieces used by Bühler and Buchholtz.

[1] *Stahl und Eisen*, 1933, vol. 53, p. 1330.

ELECTRICAL RESISTIVITY OF FARADAY STEELS; GAS ANALYSIS AND NEW PHENOMENA ON REMELTING IN RADIATION FURNACE.[1]

By CARL BENEDICKS (Metallografiska Institutet, Stockholm).

Summary.

(1) *Determinations of Electrical Resistivity.*—The electrical resistivity has been determined, using the Gallander principle, of eighteen small specimens from the material prepared by Faraday. The accuracy of the determinations on suitable specimens amounts to about $\pm$ 1%. The effects of an insufficient thickness and surface of the specimen have been examined; the resulting errors scarcely exceed a few per cent. In three cases, where the resistivity had already been determined by other methods, the agreement was satisfactory.

On the whole, the resistivities found agree fairly well with those calculated according to the author's formula, and somewhat better still when using individual coefficients for the different added elements in solid solution. It is noteworthy, however, that the steels containing gold show unexpectedly high resistivities, while the rhodium steels in one specimen yield a very high, and in the other, a very low resistivity. The influence of platinum, previously unknown, has been found to correspond to 1 atomic % of platinum increasing the resistivity by 7 microhms per cm. per sq. cm.

(2) *Gas Analysis of One Sample, Remelted in the Radiation Furnace.*—One of the Faraday specimens was melted in the radiation furnace on two occasions, and the occluded gases were measured and analysed. In this connection a novel phenomenon, occurring with unilateral radiation, is described; sharp corners in a solid, bright specimen undergoing fusion show a remarkable resistance to melting, and give rise to sharp protuberances, elongated in the direction of the radiation. ¶ Another noteworthy phenomenon observed pertains to capillarity; on heating in a high vacuum, pure iron does not wet the crucible, while carbon steel does, this difference being due to a slight chemical reaction taking place in the latter case.

I.—Introduction.

It was suggested to the author by Sir Robert Hadfield, Bt., F.R.S., who had devoted considerable attention to the examination of the steel specimens prepared by Faraday,[2] that it would be of interest to subject one of them to melting in the radiation furnace [3] installed

[1] Received January 20, 1936.

[2] Sir Robert Hadfield, *Philosophical Transactions*, 1931, A, vol. 230, p. 221: "Faraday and his Metallurgical Researches." London, 1931.

[3] Faraday was actually present in Florence, with Sir Humphry Davy, at the heating of diamond in oxygen, using concentrated solar radiation; had sufficient power been available in Davy's carbon arc, it seems quite probable that Faraday would have applied this new source of heat for melting purposes.

at the Metallographic Institute of Stockholm.[1] The author readily fell in with the suggestion, and proposed that simultaneously a determination should be made of the gas content—a reliable vacuum extraction method being already worked out there.[2]

At the same time, it seemed advisable to supplement the knowledge of the physical properties of the Faraday specimens already acquired by determining their electrical resistivity—known only for three specimens—utilising a method which permits this determination on very small, irregular specimens possessing a plane surface.

Thanks to the courtesy of the Managers of the Royal Institution, a small collection of specimens, selected by Sir Robert Hadfield, was sent to Stockholm. The determinations proposed having been accomplished, the results are now presented.

II.—Determinations of Electrical Resistivity.

(1) *Method and Apparatus Used.*

The principle of the method used, enabling determinations to be performed on very small and irregular specimens, is that first proposed by Gallander;[3] a direct current is sent through a plane, unlimited surface by means of two contact points a, d; the potential drop is measured between two intermediate points b, c, and is proportional to the resistivity of the substance. This method was used on small specimens by the author[4] (determinations on Ce, La, Pr, Nd, Ge, &c.) using a special bridge. The method was studied by Herlin[5] in his thesis for the doctorate. An improved method of measuring the small resistances concerned was given by Esmarch.[6]

A brief description of the method may be given here (*see* Fig. 1) : a, b, c, d are the four points, pressed against the specimen to be examined; R_1 and R_1' are constant and similar manganin resistances (100 ohms), as also are R_2 and R_2' (1000 ohms); W is a variable resistance (0–100 ohms); AB is a thick manganin wire (length 70 cm., dia. 1·5 mm.; the ends are shunted with a 2-mm. copper wire, so that L corresponds to a much thicker wire). The experimental arrangement is designed so as to exclude parasitic

[1] C. Benedicks and J. Härdén, *Zeitschrift für technische Physik*, 1931, vol. 12, p. 234; *Teknisk Tidskrift*, 1931, vol. 61, p. 149.

[2] G. Ericson and C. Benedicks, *Jernkontorets Annaler*, 1931, vol. 115, p. 549.

[3] A. Gallander, *Mitteilungen des internationalen Verbands für die Materialprüfungen der Technik*, 1912, Bd. II., Nr. 11, IX., pp. 1–8. Swedish Letter of Patent No. 33927. Stockholm, 1912.

[4] C. Benedicks, *Internationale Zeitschrift für Metallographie*, 1915, vol. 7, p. 225; *Svensk kemisk tidskrift*, 1916, vol. 27, p. 136; *Jahrbuch der Radioactivität und Electronik*, 1916, vol. 13, p. 351.

[5] E. Herlin, "Methoden zur Bestimmung des elektrischen Widerstandes und der Thermokraft an Körpern von geringen Dimensionen." Inaug.-Dissertation (Stockholm), Upsala, 1919. *Jernkontorets Annaler*, 1919, vol. 103, p. 449.

[6] W. Esmarch, *Annalen der Physik*, 1922, iv., vol. 69, p. 255.

thermo-electric forces. E is a 10-V. storage battery, G a mirror galvanometer (type: Zernike, Kipp, and Zonen, Delft; 1 mm. = 10^{-8} V.).

The first operation is to adjust the bridge; G is connected, through the switch C, to the point d, the contact D being disconnected; W is adjusted so that the current in G vanishes.[1]

G then being connected to the point c, and the contact D being closed, the movable contact point F is adjusted so that no current passes through G.

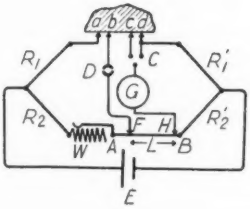

FIG. 1.

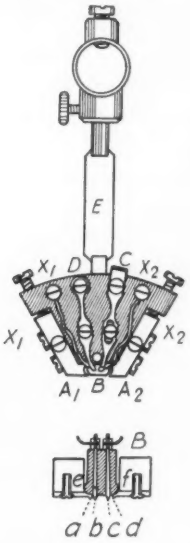

FIG. 2.

The unknown resistivity σ is then obtained from the formula

$$\sigma = K \cdot \frac{R_1}{R_2} \cdot L,$$

where L is the length of wire between F and the fixed point H, and K a constant for the apparatus, which may be determined on large regularly shaped specimens, the resistivities σ_{Thomson} of which have been previously determined (with the Thomson bridge).

The essential part of the experimental arrangement is the component carrying the contact points (*see* Fig. 2). The two pieces A_1, A_2 (adjustable, but firmly attached to the base of ebonite) are

[1] The current passing through R_1 and R_1', and that through the other branch, containing R_2 and R_2', are then in the relation $R_2 : R_1$.

provided with a bottom portion of steel carrying the outer points a, d (distance apart 4·0 mm.). An ivory piece B holds the inner points b, c, which are 3·0 mm. apart, and placed symmetrically with respect to ad. The position of B is exactly defined by slightly projecting lugs e, f; the points b, c are pressed against the specimen by two steel springs C, D. The whole apparatus, carried by a thin steel spring E, is pressed against the specimen by means of a screw, as depicted in Fig. 7 (Plate XL.), the rotation of which causes the contacts to bear against the specimen, by means of a shaft fitting into a socket near B. The points are visible in detail in Fig. 8.

(2) *Preliminary Determinations.*

(*a*) *The Constant* K.

The value of K was determined, *i.e.*, the apparatus was calibrated, on different materials, as indicated in Fig. 3. It will be

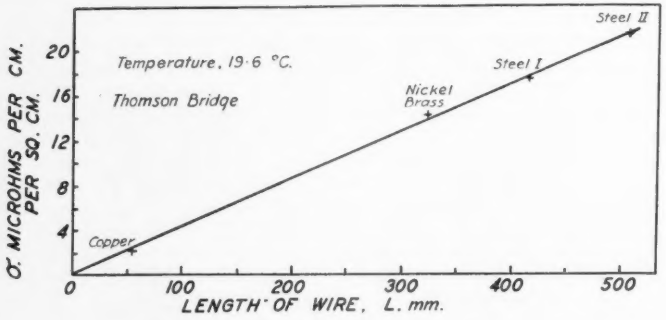

FIG. 3.

seen that while a slight deviation is found for nickel brass, the other determinations nearly coincide with a straight line through the origin. The value used was $K = 10 \cdot \sigma_{\text{Thomson}}/L = 0{\cdot}4206$ microhm per cm. per sq. cm. per mm.

(*b*) *Influence of the Thickness of the Specimen.*

The Faraday specimens being in some cases rather thin, some preliminary tests were made in order to examine the influence of the thickness. For this purpose small specimens with a surface 7 mm. × 10 mm. and of different thicknesses d, were made from the same steel. The values of L found for different values of d are given as circles in Fig. 4. Though varying slightly (which is natural since they represent different pieces!), these determinations indicate that the formula used, *viz.*,

$$\sigma = 0{\cdot}04206 \cdot L,$$

is strictly valid when the thickness d is 4 mm. or more. For $d < 4$ mm., L becomes too great, but even when $d = 2$ mm. the increase of L does not amount to more than 0·8%.

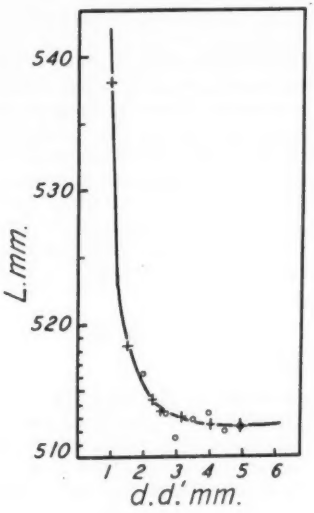

FIG. 4.

(c) *Influence of Proximity to the Edge of the Specimen.*

If the point electrodes are placed too close to an edge, the current lines will obviously be similarly affected, and the values obtained for L and σ will be too high. Hence, observations were made on a steel specimen with varying distance d' from the points to the nearest, parallel edge. The results are plotted as crosses in Fig. 4. These lie on a smoothly bent curve, and show that a strictly correct result is obtained if the distance d' amounts to 4 mm. or more. This signifies that, in order to avoid any correction, the width of the specimens should not be less than 2×4 mm. $= 8$ mm.

The curve shows, however, that the error amounts to only 1% when d becomes as low as 1·6 mm. Hence, a large portion of a given surface may be used for determinations.

These check experiments are in fairly good agreement with those obtained earlier by Herlin.

(d) *Accuracy of the Method.*

It follows from the above check tests that a prismatic steel specimen, in order to give strictly correct results with the present

apparatus, should have a minimum volume of about 8 mm. × 8 mm. × 4 mm. = 0·26 c.c., or in steel, a mass of about 2 g. The general accuracy of the method, when using large, homogeneous specimens, may be estimated at ± 1%. Allowing errors of this magnitude, specimens of a much smaller size than that indicated may be used.

If a specimen is extremely small, the best method of determining the necessary correction seems to be as follows : From a homogeneous material of known resistivity a blank specimen is obtained, of approximately the same shape and size as the specimen to be examined ; the apparent resistivity of the blank specimen, compared with its known resistivity, gives the correction necessary. In the present case it was not found necessary to introduce such corrections.

It should be added that the principal source of error consists in actual flaws or cracks, occurring in the specimen. Consequently, single high values of L may be rejected.

(3) *Actual Determinations.*

(*a*) *Faraday Specimens.*

The Faraday specimens at the disposal of the author are indicated in Table I., in which the chemical compositions are given [1] together with the weights of the specimens available.

The observed resistivities σ are given in microhms per cm. per sq. cm. in the fifth column from the end. The temperature was about 20° C.

For the three smallest specimens (23/*C*2–3 ; 26/*C*3–2 ; 58/*E*2–10) the values have been indicated as probably too high ; according to the above check experiments, the error to be expected, however, should scarcely amount to more than a few per cent.

Regarding the determinations the following comments may be made.

Several of the specimens tested showed a certain degree of heterogeneity. Thus, specimen 16/*C*1–5—the largest of the present specimens, selected for melting in the radiation furnace—showed several portions where the resistivity was about 10% greater than the value given in the table (18·3). On sawing through the specimen, several oxide inclusions were actually found. The fact that after melting the resistivity was lower (17·7) may be in part due to a removal of slag. In specimen 14/*C*1–3 variations were found amounting to 3%, in 26/*C*3–2 to 2%. The middle portion of 3/*A*3 was 2% lower than the end portions, while the middle of 2/*A*2 gave a value 7% too high—it was rejected in the average value as being probably due to some defect or heterogeneity.

[1] Sir Robert Hadfield, *Philosophical Transactions*, 1931, A, vol. 230, p. 251 : "Faraday and his Metallurgical Researches," p. 164, Table V. London, 1931.

TABLE I.—*Resistivities of Faraday Specimens.*

Hadfields No.	Mark (Stamped).	Weight. Grammes.	C, %.	Si, %.	S, %.	P, %.	Special Elements. %.	Au, %.	Ag, %.	Pt, %.	Rh, %.	Obs. σ. Microhms per cm. per sq. cm.	Calc. σ_1. Microhms per cm. per sq. cm.	Calc. σ_2. Microhms per cm. per sq. cm.	Δ_1 ($\sigma_{obs.} - \sigma_{1\,calc.}$).	Δ_2 ($\sigma_{obs.} - \sigma_{2\,calc.}$).
2	*A2*	8	0·69	0·02	...	...	...	...	...	0·80	...	17·7	16·4	17·7	+ 1·3	0·0
3	*A3*	5·5	0·92	0·28	0·021	0·030	{ Mn 0·05 Cu 0·02 }	...	...	0·73	...	20·0	21·0	21·9	− 1·0	− 1·9
7	*B4*	1·5	1·33	0·12	...	...	...	0·00	Trace	0·42	...	24·2	24·3	(19·1)	+ 2·5	(+ 5·1)
8	*B5*	1·5	1·03	0·31	...	...	...	0·31	1·34	0·00	...	24·3	21·7	23·7	+ 2·6	+ 0·6
9	*B6*	3·5	0·92	0·33	...	...	...	0·00	0·00	1·17	...	21·1	22·1	(24·9)	− 1·0	− 3·8
10	*B7*	2	0·86	0·47	...	...	{ Mn 0·04 Ni + Cu 0·07 }	0·00	1·20	...	...	25·5	21·0	25·2	+ 4·5	+ 0·3
11	*B8*	1·4	1·10	0·19	...	...	...	0·88	0·15	0·00	...	25·0	18·9	19·8	+ 6·1	+ 5·2
12	*C1–1*	2·5	1·24	0·14	...	...	...	...	0·46	0·00	...	18·3	17·8	18·9	+ 0·5	− 0·6
14	*C1–3*	3	0·94	0·33	...	...	Ni + Cu 0·07	...	0·00	0·74	...	20·6	20·2	22·1	+ 0·4	− 1·5
16 *	*C1–5*	30	0·77	0·24	...	...	...	0·00	0·00	0·00	...	18·3	17·5	18·1	+ 0·8	+ 0·2
16 †	*C1–5*	30	0·77	0·24	...	...	...	...	...	...	...	17·7	17·5	18·1	+ 0·2	...
19	*C1–8*	3·5	1·15	0·24	...	...	...	0·60	...	...	...	22·0	18·3	18·8	+ 3·7	+ 3·2
23	*C2–3*	1	0·16	0·14	...	...	...	0·90	Trace	0·00	...	< 24·9	17·8	18·7	+ 7·1	+ 6·2
26	*C3–2*	0·6	0·24	...	...	0·107	Ni + Cu 0·13	...	0·00	...	...	< 16·3	12·9	17·6	+ 3·4	− 1·3
29	*D2*	9	1·06	...	...	...	Cu 2·79	0·00	...	...	...	22·6	...	...	...	...
32	*D5*	5	1·09	0·07	0·029	0·051	Cr 0·63	0·00	0·00	0·00	...	20·4	19·1	20·0	+ 1·3	+ 0·4
58	*E2–10*	0·7	0·07	0·14	...	0·128	...	...	...	...	...	< 12·0	12·4	13·1	− 0·4	− 1·1
68	*F2*	9	1·75	0·10	1·76	0·078	Ni + Cu 0·06	...	...	...	...	24·2	...	...	...	...
69	*F3*	5	1·75	0·10	1·73	0·078	...	...	...	...	...	27·2	...	...	...	...

* Specimen selected for melting in the radiation furnace.

† Same after melting.

On the other hand, several of the specimens showed remarkable homogeneity. Thus, 9/*B*6, containing 1·17% of rhodium, gave everywhere on the surface almost identically the same resistivity; the variations did not exceed $\pm$ 0·2%.

On the whole, the homogeneity was found to be fairly good.

(*b*) *Comparison with Hadfield's earlier Determinations.*

Resistivity determinations had already been made on three specimens prepared in the form of Chevenard test-pieces.[1] The values found are given in Table II.

TABLE II.—*Comparisons with Previous Determinations.*

Material.	Hadfield's Research No.	Mark.	Resistivity.	
			Previous Value. Microhms per cm. per sq. cm.	Present Value. Microhms per cm. per sq. cm.
Rhodium steel .	9	*B*6	19·7	21·1
Platinum steel .	14	*C*1–3	20·0	20·6
Wrought iron .	57	*E*2–9	11·9	...
Wrought iron .	58	*E*2–10	...	12·0

The analyses of 57/*E*2–9 and 58/*E*2–10 are not quite identical, but the difference is insignificant.

It will be seen that the agreement between the determinations made with the usual fall of potential method and the present micro-method, as it may be termed, is fairly good.

(*c*) *Discussion of the Results.*

It is interesting to compare the resistivities now found with those obtained by calculation in accordance with earlier researches. This will be attempted in two different ways: (1) By using the author's formula, which assumes equivalence between the influences of 1 atomic % of different added elements in solid solution, and (2) by using individual coefficients for the added elements.

(1) *Using the Author's Formula.*—According to the author's formula [2] the resistivity σ may be written :

$$\sigma = 7{\cdot}6 + 26{\cdot}8\ \Sigma C \text{ microhm per cm. per sq. cm.},$$

where ΣC is the sum of the "carbon values" of the amounts of carbon, silicon, manganese, &c., in solid solution, *i.e.*,

$$\Sigma C = \mathrm{C} + \frac{12}{28{\cdot}4}\,\mathrm{Si} + \frac{12}{55{\cdot}0}\,\mathrm{Mn} + \ \ldots$$

[1] Sir Robert Hadfield, *Philosophical Transactions*, 1931, A, vol. 230, p. 286: "Faraday and his Metallurgical Researches," p. 204. London, 1931.

[2] C. Benedicks, *Zeitschrift für physikalische Chemie*, 1902, vol. 40, p. 545: Thesis, Upsala, 1904, p. 105. This formula is equivalent to the assumption that 1 atomic % of any element in solution causes an increase of sensibly 5·7 microhms per cm. per sq. cm. (limiting value, for dilute solutions).

In annealed steels, with a carbon content exceeding 0·5 or 0·6%, a constant amount of carbon (0·27%) in solution is assumed, the excess carbon content being present as cementite, apparently exerting only a very weak influence.[1]

The resistivities calculated in this way are indicated by σ_1 in Table I.[2] It will be seen that about half the number of observed values are in good accord with σ_1. Though naturally considerable differences occur, it is remarkable that, on the whole, these extremely small irregular specimens have given such good agreement with the results of later measurements on larger specimens—as represented in the formula.[3]

(2) *Using Individual Coefficients.*—The equivalence of 1 atomic % of different dissolved substances represents only a first approximation, somewhat analogous to the assertion that the atomic heat of a solid element is a constant (and equal to about 6).

Going into details, the author [4] later made an evaluation from existing data of individual coefficients for the different elements in solid solution, in the manner already described (for carbon, manganese, nickel, and silicon) by Le Chatelier.[5]

The increases in resistivity caused by the addition of one atom per 100 atoms of the alloy were found to be those given in Table III. (column 1). A similar evaluation was then made by Norbury [6] (column 2).

On the whole, the differences, as seen in the last column, are scarcely greater than could be expected, the data available generally being scanty. The following two remarkable differences, however, occur; for cobalt, column 1 gives the single value existing in 1916, by Burgess and Aston, while the extremely low value of column 2 is founded on a figure given by Hônda; for nickel the figure (4·0) in column 1 was deduced from the determinations of Barrett, Brown, and Hadfield (3·7), Burgess and Aston (5·5), Enlund (3), Le Chatelier (3–7), Portevin (2), and Ruer and Schuz (3·6), while that in column 2 (1·5) was evaluated from determinations only of Portevin and of Hônda.

An inspection of the original observations makes it probable that the values in column 2 are actually too low (which does not,

[1] For the influence of cementite carbon, *cf.* F. Stäblein, *Zeitschrift für Physik*, 1923, vol. 19, p. 209.

[2] No calculation could be made for the sulphur-containing specimens 68/*F*2, 69/*F*3, as the sulphur occurs mainly in a precipitated form.

[3] It may be pointed out that several authors consider the value 7·6 of the formula—expressing the resistivity of pure iron—to be too low. Hence, it is noteworthy that F. C. Thompson (*Philosophical Magazine*, 1916, vol. 31, p. 357) with a pure remelted iron obtained the figure 7·56 and even still lower figures with particularly coarse-grained specimens.

[4] C. Benedicks, *Jernkontorets Annaler*, 1916, vol. 71, p. 35.

[5] H. Le Chatelier, "Contribution à l'étude des alliages," p. 416. Paris, 1901.

[6] A. L. Norbury, *Journal of the Iron and Steel Institute*, 1920, No. I., p. 627: *Transactions of the Faraday Society*, 1921, vol. 16, p. 570

TABLE III.—*Increase in the Resistivity of Iron, caused by 1 Atomic % of the Added Element in Solution.*

Element.	(1) Benedicks, 1916. Microhms per cm. per sq. cm.	(2) Norbury, 1926. Microhms per cm. per sq. cm.	Difference, Δ. Microhms per cm. per sq. cm.	Element.	(1) Benedicks, 1916. Microhms per cm. per sq. cm.	(2) Norbury, 1926. Microhms per cm. per sq. cm.	Difference, Δ. Microhms per cm. per sq. cm.
Silver .	5·5 *	...	...	Molybdenum	5·4	5·8	− 0·4
Aluminium	6·4	5·8	+ 0·6	Nitrogen .	...	3·6	...
Arsenic .	9·8	...	...	Nickel .	4·0 *	1·5	+ 2·5
Gold .	...	3·9 *	...	Phosphorus	6·7 *	6·1	+ 0·6
Bismuth .	5 ?	...	...	Antimony .	17 ?	...	...
Carbon .	6·5 *	6·9	− 0·4	Silicon .	6·9 *	6·9	0·0
Cobalt .	6·1	1·0	+ 5·1	Tin . .	8·0	...	...
Chromium	4·6 *	5·0	− 0·4	Titanium .	5·5 ?	...	...
Copper .	4·2 *	4·5	− 0·3	Vanadium .	6·1	4·6	+ 1·5
Manganese	6·0 *	5·2	+ 0·8	Tungsten .	6·4	4·9	+ 1·5

* These are the coefficients which were actually used.

however, exclude the possibility of the corresponding values of column 1 being too high). They illustrate well, however, in the case of iron, the important fact, pointed out by the author (*loc. cit.*) in 1916 (especially for copper, silver, gold, platinum) and in more detail by Norbury (*loc. cit.*) in 1921 (for iron, nickel, copper, silver, gold), that the nearer the solute stands to the solvent in the periodic system, the less, generally, is the increase in resistivity caused by the solute.

In the calculations the individual coefficients actually used were those marked with an asterisk in Table III.[1] The resulting resistivity values are given as σ_2 in the third column from the end of Table I. Regarding this the following further comments may be made.

On the whole, the differences $\sigma_{obs.} - \sigma_{2\,calc.}$ are slightly lower than the differences $\sigma_{obs.} - \sigma_{1\,calc.}$, showing that the individual coefficients give a somewhat more accurate result. To aid comparison, $\sigma_{obs.}$ and $\sigma_{2\,calc.}$ are plotted in Fig. 5.

Considerable deviations are shown by the specimens 11/*B*8, 19/*C*1–8, and 23/*C*2–3, containing 0·88, 0·60, and 0·90% of gold. The $\sigma_{obs.}$ figures are much higher than those calculated by the use of the coefficient 3·9 computed by Norbury. To bring the auriferous steels into agreement with the calculations, the coefficient must be changed to about 21 microhms per 1 atomic % of gold; this value is more than five times greater than Norbury's, and therefore appears improbable—especially since only a small proportion of the gold might be in the state of solid solution.

[1] The method of calculating the influence of cementite carbon was the same as before.

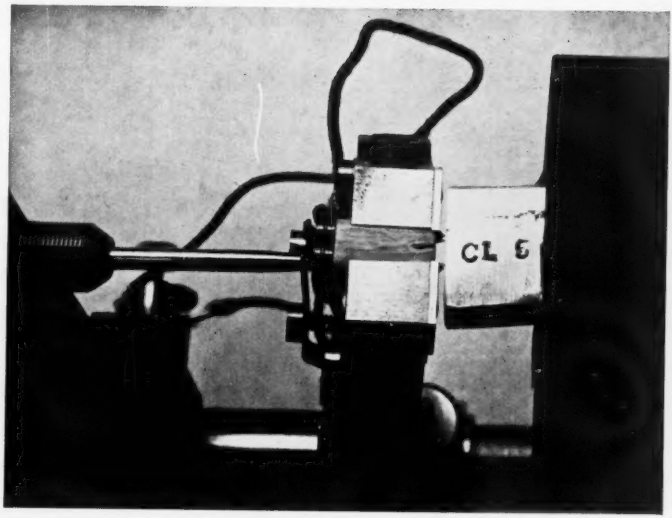

FIG. 8.—Resistivity Apparatus, showing contacts.

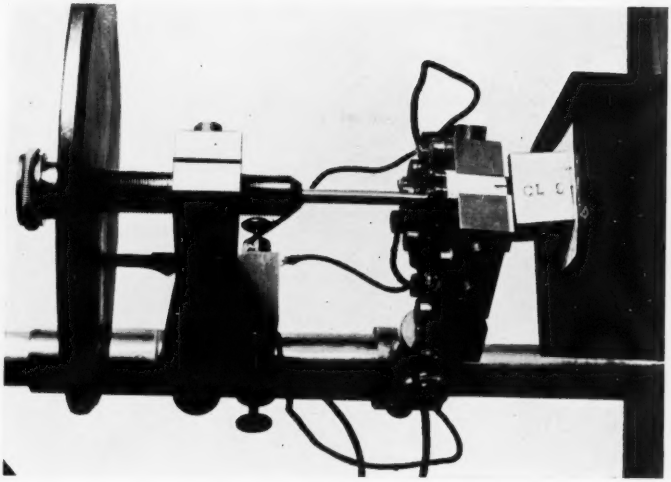

FIG. 7.—Resistivity Apparatus.

[*Benedicks.*

[*To face p.* 464 P.

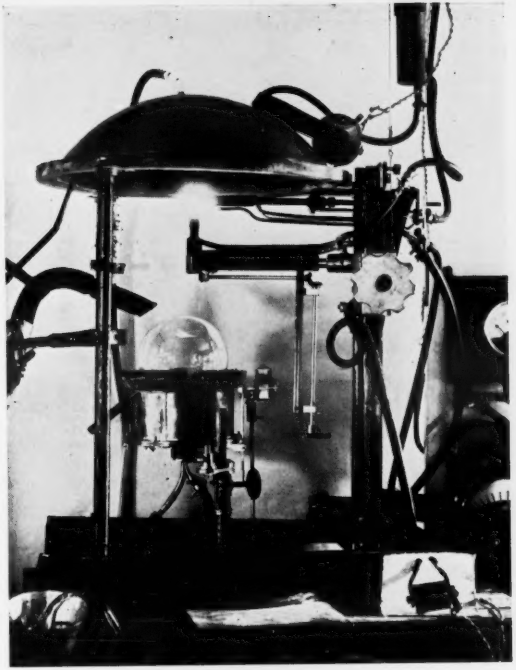

FIG. 9.—Radiation Furnace.

FIG. 10.—Crucible and Focusing Arm.

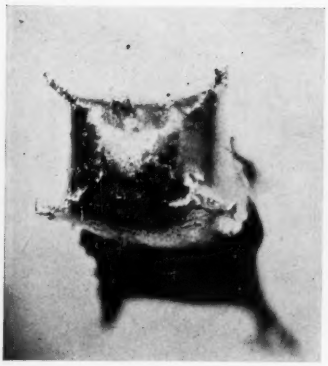

FIG. 11.—Specimen No. I. after partial Melting.

FIG. 12.—Specimen No. II. after Remelting.

FIG. 13.—Faraday Specimens. × 1·2.

[*Benedicks.*

The specimens are actually extremely small (weighing 1·4, 3·5, and 1 g.), so that the determinations may be influenced by heterogeneity or edge effects. In any case, the influence of gold merits further examination.

The specimens containing platinum (2/*A*2, 3/*A*3, 8/*B*5, 10/*B*7, 14/*C*1–3) are of special interest, no determinations of the influence of this metal being known. Assuming the coefficient to be 7 microhms per 1 atomic % of platinum, the values calculated in Table I. come very near to those observed.

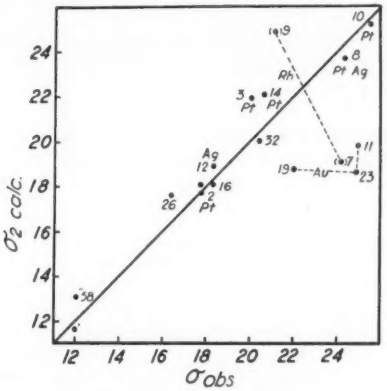

FIG. 5.

The specimens containing rhodium (7/*B*4, 9/*B*6) are also of special interest, since the influence of this metal has not been determined. Its coefficient was similarly assumed to be 7 microhms per 1 atomic % of rhodium but 7/*B*4 has a much higher value and 9/*B*6 a much lower value for $\sigma_{obs.}$ than those calculated, so that no conclusion can be drawn. These departures are all the more striking, as 9/*B*6 was, as already stated, found to be extremely homogeneous.

For the samples containing 0·31 and 0·41% of silver (8/*B*5, 12/*C*1–1) the observed and calculated values are in good harmony.

The single wrought-iron specimen (58/*E*2–10), though extremely small (0·7 g.), shows a remarkably small difference, especially when compared with $\sigma_{1\ calc.}$ (this is also plotted in Fig. 5).

(3) *Conclusion.*

The resistivities determined for the Faraday specimens, although these are in some cases very small, on the whole are seen to agree well with the figures calculated by modern methods. This is so, whether the calculation is made simply by the author's formula, or by using

individual coefficients for the different dissolved elements. In the latter case, however, the agreement found is slightly better.

For platinum, where no coefficient was known, the following value has been deduced: Increase in resistivity = 7 microhms per cm. per sq. cm. per 1 atomic % of platinum.

Irregularities are shown by the samples containing gold and also rhodium.

The above determinations and some of the calculations were made by Mr. S. F. Thunberg.

III.—Gas Content of a Sample of Faraday Steel, Remelted in the Radiation Furnace.[1]

(1) *Method and Apparatus Used.*

It was suggested by Sir Robert Hadfield that a specimen from among the steels prepared by Faraday should be melted in the radiation furnace, introduced and described by Benedicks and Härdén some time ago.[2]

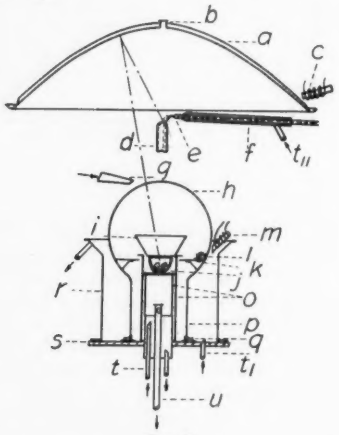

Fig. 6.

Several improvements in the design of the apparatus have since been made (*see* Fig. 6). The water-cooled elliptical copper reflector *a* (55 cm. effective opening, by 20 cm. focus) has a gilt surface to prevent tarnishing; the negative electrode *e* (7·4 mm. dia.) is placed

[1] Experiments performed by J. Härdén (deceased); gas analyses by G. Ericson.

[2] C. Benedicks and J. Härdén, *Zeitschrift für technische Physik*, 1931, vol. 12, p. 234: *Teknisk Tidskrift* (*Stockholm*), 1931, vol. 61, p. 149.

at an angle of about 85° to the positive electrode *d* (22 mm. dia.). The arc is regulated by a suitable magnet *c*, placed outside the reflector.

The specimen to be melted (*l*) is placed on a collapsible molybdenum shelf *k*, in a pocket near the wall, inside a glass bulb *h* (18 cm. dia., volume 3 litres), in the centre of which the crucible *j*, of sintered Al_2O_3, is placed.

After the exhaustion and preheating of the crucible, the specimen is lifted by means of the magnet *m* above the crucible and allowed to drop into it. The bulb is cooled by means of a water-jacket *r*, and an air jet *g*.

Fig. 9 (Plate XLI.) shows the furnace at work (with some further new details not referred to above). Fig. 10 illustrates the melting vessel; a pointer, seen at the front, serves the purpose of facilitating the focusing.

As it was decided to collect and analyse the gases liberated on fusion, an ordinary gas analysing apparatus was connected to the furnace.

(2) *Working Operations.*

The metal to be melted—at present not exceeding 12 g., and preferably cut into two or three pieces—is placed in the pocket on the shelf; the crucible is placed in position, and the bulb sealed (by means of Chatterton's compound No. 1) in the sealing groove *q* of the base plate, after which the vessel is exhausted to less than 0·0001 mm. of mercury.

The crucible is then heated by reflection from the arc, which carries a current of about 100 amp. at 48 V., for about 5 to 10 min.; this is repeated a few times. The current is then increased in several stages up to about 320 amp., until the evolution of gas becomes very small (blank value).

The specimen is now introduced into the crucible and heated; the fusion of 10 g. required, as a rule, about 8 min., with 320–350 amp.

The melting is generally found to commence in the middle of the charge, where soon a lively agitation sets in, mainly due to the gases being liberated, throwing small globules of fused metal upon the walls of the crucible. Some metal also sublimes and condenses on the glass wall. The scattered metal will account for a slight loss in weight, of about 3–5%. It sometimes happens that the main portion of the charge is rapidly liquefied, while the corners of the piece, if it is angular in form, may remain solid, as mentioned later.

(3) *Description of the Sample Employed.*

The original sample placed at the author's disposal, No. 16/*C*1–5, consisted of an irregular, rectangular bar about 9 × 13·5 × 34 mm., weighing 30·3 g.

The analysis, as ascertained by Sir Robert Hadfield (*loc. cit.*),

was carbon 0·77%, silicon 0·24%, and iron 99·10%; total 100·11%. Several inclusions and oxide streaks extended throughout the whole piece.

The *specific gravity* was found to be 7·83, *i.e.*, the specific volume was 0·1277.

Using the data previously determined,[1] the specific volume of an annealed steel of the above analysis should be 0·12756 c.c. Thus the specific volume found is fairly normal; so far as it is actually found to be slightly higher than the calculated value, this may partly be explained by the oxide streaks.

The electrical resistivity, as determined by the method already described, was found to be 18·3 microhms per cm. per sq. cm., which is also fairly normal (calculated value 17·5 or 18·1).[2] From the sample two pieces were cut off, weighing respectively (I.) 9·171 g. and (II.) 10·183 g. (filings = 0·45 g.). Specimen No. II. was observed to contain more inclusions than No. I. This was actually borne out by the specific volumes now determined: No. I., 0·1276; No. II., 0·1279.

(4) *Trial No.* 1.

Specimen No. I. was placed in the pocket of the apparatus. The latter was exhausted and preheated as previously explained. The volume of the "blank" gas liberated was progressively read. The total volume of the blank gas liberated during a period of about 8 min.—which, according to the preliminary experiments should be required for the melting of the specimen—was 0·58 c.c. at 20° C., and a pressure of 760 mm. of mercury. Its composition was found to be:

CO_2	0·06 c.c.	= 0·06 c.c. O_2
CO	0·40 ,,	= 0·20 ,,
		0·26 c.c. O_2
H_2	0·06 ,,	
N_2	0·06 ,,	
	0·58 c.c.	

The specimen was then charged in the crucible (with the current switched off). The amount of gas liberated was again successively read at regular intervals. Signs of incipient fusion were observed on the surface of the specimen, when a small drop of slaggy substance from the positive carbon fell down on the glass bulb, causing a minute crack there.[3] This caused a sudden augmentation of the regular increase of the gas volume observed. On account of this, the arc was at once shut off (after a little more than 4 min.). The

[1] C. Benedicks, Thesis, Upsala, 1904, p. 29. [2] *See* above.

[3] In the numerous preliminary trials, such drops had occurred more or less frequently, but since the brand of carbon now used was introduced this trouble has practically disappeared.

gas volume read off before the sudden increase was 3·16 c.c., and is designated as V_1; it must be slightly less than the correct gas volume. The gas, being contaminated with air, could not be analysed. The air leakage caused but a slight discoloration of the specimen, which had not had time to melt down. Its resistivity was estimated to be 17·7 microhms per cm. per sq. cm.

After cleansing the surface of the specimen and replacing the bulb by a new one, the trial was continued without accident. The blank value was practically the same as before; the total gas volume collected during the second period of heating was $V_2 = 4{\cdot}66$ c.c. The gas analysis was as follows :

CO_2	0·16 c.c.	= 0·16 c.c. O_2
CO	3·88 ,,	= 1·94 ,,
		2·10 c.c. O_2
H_2	0·33 ,,	
N_2	0·29 ,,	
	4·66 c.c.	

Hence the gas due to the specimen itself had the following composition :

O_2	2·10 − 0·26 = 1·84 c.c.	= 0·026%
H_2	0·33 − 0·06 = 0·27 ,,	= 0·00024%
N_2	0·29 − 0·06 = 0·23 ,,	= 0·0029%

It will be seen that the blanks observed are rather low; this, however, by no means excluded considerable systematic errors.

Now, assuming that the first portion V_1 of the gas had the same average composition as V_2—which seems very probable—it is represented by the following figures :

CO_2	0·11 c.c.	= 0·11 c.c. O_2
CO	2·63 ,,	= 1·32 ,,
		1·43 c.c. O_2
H_2	0·22 ,,	
N_2	0·20 ,,	
	3·16 c.c.	

Deducting now the blank value for a 4-min. period, or $\frac{4}{8}$ of 0·58 c.c. = 0·29 c.c., the first gas volume V_1 gives these values :

O_2	1·43 − 0·13 = 1·30 c.c.	= 0·018%
H_2	0·22 − 0·03 = 0·19 ,,	= 0·00017%
N_2	0·20 − 0·03 = 0·17 ,,	= 0·0021%

Adding the figures obtained from V_1 and V_2, one finally obtains the total gas liberated, 7·82 c.c. (from 9·17 g. weight), of the composition given in Table IV.

The solidified specimen was found to have a *perfectly bright*, unoxidised surface, and also to possess certain *sharp, knife-like protuberances*, as is clearly seen in Fig. 11 (Plate XLII.).

This is a novel phenomenon which, so far as the author is aware, has not previously been described, and which will now be discussed.

(5) *A Melting Phenomenon in Unilateral Radiation.*

In all the preliminary experiments with the radiation furnace, when the heating was simply conducted in the air, the concentrated radiation was found extremely effective in melting iron. Under these conditions, the surface of the solid iron obviously becomes oxidised, so as to be more or less " black." This signifies a strong absorption of the radiation, *i.e.* easy melting.

When, on the contrary, as in this experiment, the presence of oxygen has been carefully eliminated, the metal preserves its bright, silvery surface. Consequently, *its absorptive power will be much less* than when it is slightly oxidised, and the metal appears much more refractory than when the surface is dark.[1]

Consider a metal, say iron, in the shape of a cube which is exposed to radiation from all sides, as in an ordinary furnace. Its corners are then the most exposed to liquefaction, on account of the radiation heating the three adjacent surfaces. The cube, on melting, will consequently assume a more or less regular spherical form.

Assume, on the other hand, that the cube is exposed to radiation from only one side—as in starting up the radiation furnace—and falling perpendicularly on to the horizontal surface of the cube; in this case the corners will behave in quite a different manner. They will apparently be the most heat-resisting portions, since the two vertical surfaces at each corner, being heated *by conduction* (from the horizontal surface), will radiate (secondary) heat, *thus cooling the actual corner*.

Naturally, the vertical surfaces near the corner will melt if the radiation is strong enough, though the actual corner remains solid. The melting of the outer portions will continue *up to a very short distance* from the diagonal through the corner (in the horizontal surface). The lamella along this diagonal will finally be so thin as to be well cooled laterally from both sides. In this state, the sharp lamella will be *very resistant to liquefaction*; the heat is taken up by only a very narrow surface, but is given off through the large side surfaces.

These considerations seem to explain well the characteristic appearance of Fig. 11. The one-sided character of the radiation used is obviously related to (1) the comparatively short heating

[1] The fact that the melting becomes less effective *in vacuo* than, say, in nitrogen, is also dependent on the fact that the inside of the glass bulb receives a mirror of vaporised iron which is formed more quickly *in vacuo* than at higher pressures.

period, and (2) the bright and white surface of the crucible, causing it to be slowly heated.

It might be objected, however, that a slight heat absorption by the metal surface cannot be essential; that is, in the same proportion as the rate of heat absorption by the horizontal surface is increased, the radiation from the lateral surfaces would also increase. This, however, is incorrect; if the absorption coefficient of the heated surface is high, the intensity of the radiation causes immediate liquefaction, leaving no time for the radiation from any considerable lateral surface—such as could exert a sensible cooling effect.

The following general statement may be made.

A solid metallic body will necessarily show a high resistance to melting by strong unilateral radiation, *when it is elongated in the direction of the radiation*; the lateral loss of heat is then a maximum.

A pin placed in the direction of the radiation (so as to shade itself, except at the very top) represents the *maximum of resistance to melting*.[1]

The form assumed by specimen I., with sharp protuberances pointing in the direction of the cone of light used, was so typical and interesting that the specimen has been preserved in this condition.

Owing, however, to a small portion of the specimen remaining unmelted, one may conclude that the figures of the above analysis are probably slightly too low, although, considering the experimental difficulties involved, this error appears very insignificant.

(6) *Trial No. 2.*

Discussion of Gas Content.

The second trial constituted a repetition of trial No. 1, but the heating was made slightly longer, so as better to melt the specimen (No. II.) now used.

Preheating and de-gassing were carried out as before; the melting time was 9 min.

The amount of gas liberated (after deduction of the blank value, which was similar to those given above) was 15·03 c.c. The resulting analysis is given in Table IV.

TABLE IV.—*Gas Analysis of Faraday Specimen* 16/C1–5.

Gas.	Specimen I. %.	Specimen II. %.	Average %.
O_2	0·04	0·10	...
H_2	0·0004	0·0005	0·0004
N_2	0·005	0·007	0·006

[1] The phenomenon observed presents some similarity to the way in which snow is found to melt in sunshine.

Only one decimal figure has been given, on account of the considerable experimental difficulties, of which the most prominent seems to be that of preserving a constant temperature—which is necessary for obtaining reliable blank values.

The figures obtained, at least for specimen No. I., must be slightly too low, on account of the specimen not being completely liquefied. They were meant to represent the gas occurring in the specimen, and given off on fusion, but a certain amount of carbon monoxide not previously existing is necessarily formed from the reaction of the carbon of the steel with the iron oxide inclusions. By comparison, the possible reaction with the Al_2O_3 of the crucible may probably be neglected.

The fact that the oxygen content in specimen II. is considerably higher than that in specimen I. seems fully accounted for by the greater occurrence of oxide inclusions in specimen II., as already mentioned.

The oxygen contents obtained, namely, 0·04 and 0·10%, are certainly abnormal for a 0·8% carbon steel, which normally contains only, say, about 0·002% of oxygen. The figures, however, are by no means excessive; a Swedish Lancashire iron normally contains 0·10–0·14% of oxygen.[1]

As regards the hydrogen and nitrogen contents, good agreement is shown—especially considering that the first analysis would be expected to be slightly too low.

These hydrogen and nitrogen contents are slightly higher than is normal for carbon steel, but quite of the same order of magnitude. Thus, modern steels containing 0·6–0·7% of carbon have given contents of hydrogen of 0·0001–0·0003%, and of nitrogen 0·001–0·005% (analyses made in Stockholm by G. Ericson); in Bessemer steel the nitrogen content even amounts to 0·010–0·015%.

Remelting of Specimen No. II.

The surface of the solidified metal obtained was quite bright and silvery; the metal had apparently been well fused. It was, however, rather irregular in shape, this probably being due to portions of the metal having been spluttered up by the gas evolved, on to the wall of the crucible, and adhering there.

It was therefore decided to reheat the metal so as to produce, if possible, a clean and regular button—which, as has been stated, was not obtained in trial No. 1. While the vacuum used was as high as before, no attempt was made to collect gas.

During melting, which commenced in the middle, no particular agitation of the metal could be observed, which was quite natural, since the gases had been expelled previously. The button obtained now was almost as bright as before, *but still rather irregular in shape*,

[1] R. Treje and C. Benedicks, *Jernkontorets Annaler*, 1932, vol. 115, p. 165; *Journal of the Iron and Steel Institute*, 1933, No. II., p. 205.

as shown in Fig. 12, and also in Fig. 13 (*a*). This illustration depicts also a specimen similar to the original ones (Fig. 13 (*c*)), and the imperfectly melted piece No. I. (Fig. 13 (*b*)). It appears from this comparison that even in (*a*) some unchanged corners may tend to persist.

The practical conclusion to be drawn is the following: In order to facilitate a thorough melting in the radiation furnace the specimen to be melted should be slightly rounded off. (It is not impossible, however, that even in this case sharp-cornered portions would be found during melting.)

(7) *On the Adhesion between Liquid Iron and Steel and Refractory Oxides.*

Just as in trial No. 1 no regular button was obtained, it has been seen that trial No. 2 likewise failed to give this desired result. In the former case the reason was found to be a previously unnoticed radiation phenomenon; as will be seen, in the latter case also the reason lies in a phenomenon which has hitherto received little attention.

In the numerous preliminary trials, made in order to avoid risking the valuable Faraday specimen at the author's disposal, use had partly been made of a fairly pure Swedish iron, without any special difficulty in obtaining regular buttons.

In the present trials, however, the specimen to be melted (No. 16/*C*1–5) actually contained 0·77% of carbon. The question therefore arises: What is the reason for a (nearly) carbon-free iron not adhering to, or wetting, the oxide crucible, while a carbon steel evidently has a strong adhesion to, or tendency to wet, the crucible?

Now, the conditions which determine whether a given liquid will wet a given solid or not, are still rather obscure. It is possible, however, to state that *if the liquid gives rise to a chemical attack on the solid, then it will wet it* (at least, the author has long been satisfied that this is the case).

As a matter of fact, a carbon-free iron will practically not react with MgO or Al_2O_3. On the other hand, if the iron contains carbon, this will react according to the formula

$$C + MgO = CO + Mg;$$

as the reaction product, CO, is gaseous, the reaction will be accelerated *in vacuo*.

For this reason, one may expect that, *in vacuo*, molten pure iron will scarcely wet a magnesia crucible, while *molten carbon steel will definitely do so*.

The correctness of this conclusion is borne out by the following. At the Metallographic Institute quite a number of vacuum melts, made in magnesia crucibles, had been prepared by G. Ericson for another purpose. It was observed that the same crucible could be

used *repeatedly* for carbon-free iron—which was easily removed—but *only once* for carbon steel; in this case, the metal adhered so strongly that the crucible had to be entirely destroyed. In the former case, the surface of the metal was smooth, while in the latter it was finely granular, and was found to contain numerous strongly adhering magnesia particles.

These observations—which will probably be followed up later—seem to make it perfectly clear why, on melting *in vacuo*, pure iron easily gives regular buttons, while carbon steel adheres strongly to the wall of the crucible, so that no regular button is formed.

(8) *Conclusion.*

It will be seen from the foregoing, that the analysis of the gas content of the Faraday specimen 16/*C*1–5 was successfully carried out (*see* Table IV.). The hydrogen and nitrogen contents found are quite normal; the oxygen figures are rather, though not excessively, high. This is easily explained as being due to the oxide streaks, occurring more abundantly in specimen No. II. In view of the explanation given in the preceding paragraph it must be added, however, that the amount of CO obtained may to some extent be due to a reaction between the carbon of the steel and the crucible. It appears doubtful, however, whether this reaction—sufficient to cause a wetting of the crucible—may give a measurable amount of CO.

Further, the endeavour to obtain, by use of high vacuum radiation heating, the two metal pieces as quite regular buttons, was not successful. This negative result appears to be a most interesting feature, since it is found to be due to two factors scarcely previously investigated: On the one hand, a novel phenomenon exhibited with unilateral radiation, and on the other, a capillary action, that of the molten iron and steel not wetting, or wetting, the refractory oxide of the crucible.

As already indicated, the above experimental work, using the radiation furnace, was performed by the late Mr. Johannes Härdén. It is thanks to his rare ability and inventiveness, demonstrated by several new practical improvements, that this part of the work has been brought to a successful issue. It may be added that, for the elaboration of this new method of heating, which presents new technical possibilities, the main credit must be given to Mr. Härdén.

CORRESPONDENCE.

Sir ROBERT HADFIELD, Bart., F.R.S. (Past-President, London), wrote that it gave him much pleasure to send a short contribution to the discussion on this admirable paper, involving so much thought and care, by his friend Dr. Carl Benedicks.

The suggestions for a research on this subject originated from the reference in the writer's paper entitled " A Research on Faraday's ' Steel and Alloys,' " read before the Royal Society in 1931 (*Philosophical Transactions*, 1931, A, vol. 230, pp. 221–292).

He would like to express his personal indebtedness to Dr. Benedicks for the care and attention he and his colleagues had given to this interesting examination of certain specimens of Faraday's " Steel and Alloys."

As regards the tests described in Part II. of the paper, it would be agreed these made a useful addition to the knowledge of the effect of alloying elements on the electrical resistance of iron. The information was all the more valuable because of the special nature of the alloys made by Faraday, notably those containing platinum and gold. Moreover, the tests helped to demonstrate further how much information could be obtained by a skilled worker with the facilities now available, and from quite minute specimens; it would be noted that one of the specimens of which a satisfactory determination of the electrical resistance was made weighed only 0·7 g., or one-fortieth part of an ounce. Had Faraday been allowed the insight into the physical character of metals afforded by such modern resources, what might he not have achieved in his experiments with ferrous alloys!

The writer's suggestion that one or more of Faraday's specimens should be melted by Dr. Benedicks had been made chiefly with a desire to emphasise the contrast between the most modern methods of melting, as represented by Dr. Benedicks' arc radiation furnace, operating *in vacuo*, and the primitive " blast-furnace " available to Faraday and described very fully in pp. 99–101 of the writer's book on " Faraday and his Metallurgical Researches."

This, as Part III. of the paper showed, had been admirably accomplished, Dr. Benedicks' special type of arc radiation furnace having fully proved its capabilities as a laboratory melting equipment. By its aid he had, in fact, been enabled to improve the occasion and obtain some quite useful information helping to advance the knowledge of the gaseous constituents in steel, which would no doubt be read with great interest by those occupied with investigations of this nature, some of which were now so actively being pursued. Since, also, as was often the case in such competent hands, interesting and unsuspected physical effects had been brought to light, these experiments had, therefore, indeed proved to be worth while.

The " wetting " of refractories by molten steel described by

Dr. Benedicks was a matter of some practical importance, and his views connecting this with chemical attack of the liquid metal on the refractory would be noted with interest, as also the peculiar mode of operation of radiant heat in effecting melting, which his special type of furnace had enabled to be examined.

The writer was particularly pleased that his suggestions had borne fruit in the presentation of this paper relating to the valuable experiments carried out by Dr. Benedicks.

Melting by the Solar Furnace.—Some time ago, and before Dr. Benedicks took up his research on the melting of steel by radiant heat, as described in the present paper, it occurred to the writer that it would be interesting to have melted in the " solar furnace " a few of the specimens of Faraday's steel described in his (Sir Robert Hadfield's) paper to the Royal Society, also in his book, " Faraday and his Metallurgical Researches," and he had suggested to his friend Dr. Hale, Director of the Mount Wilson Observatory, Pasadena, California, that he (Dr. Hale) should carry out such experiments with his solar furnace, then under construction.

Melting by solar radiation was a fascinating subject, and it might interest the members of the Institute to know that Dr. Hale, in his valuable paper, " The Astrophysical Observatory of the California Institute of Technology," in the *Astrophysical Journal* of September, 1935, referred to the following :

> " On the roof are the 23 ft. dome of the coelostat telescope, a rolling house covering a ' solar furnace ' (consisting of nineteen 24-in. lenses and the same number of condensing lenses, equatorially mounted, which concentrate the solar rays at an immovable focus) . . ."

This solar furnace, termed irreverently by the American press " the world's most powerful burning glass," was equipped with nineteen single lenses, each 24 in. in dia., used in combination with eighteen smaller plane mirrors and nineteen condensing lenses, and concentrated sunlight within a vacuum chamber, where metals could be vaporised and studied with a spectrograph. In some preliminary experiments already made the sun's rays converged on steel wire and melted this product, to use the expression of a journalist, " with the same speed as a gas burner would melt butter."

Owing, however, to the recent arrival of the 200-in. pyrex disc for the enormous telescope at Mount Wilson, and the great pressure of work thrown upon Dr. Hale and his staff by the various matters to be arranged in connection with the erection of this immense disc, Dr. Hale had informed the writer that he feared it would be some time before it would be possible to make any progress with the experiments he had intended to take in hand with the aid of the solar furnace.

However, as soon as this 200-in. pyrex disc lens was erected, Dr. Hale was going to melt a specimen of the steel made by Faraday,

which the writer had sent Dr. Hale some time ago, namely, about 28 g. from specimen No. 10/*B*7 of the following composition :

C.	Si.	Mn.	Ni and Cu.	Pt.	Fe.
%	%	%	%	%	%
0·86	0·47	0·04	0·07	1·20	97·34

Half of this specimen was to be returned to the writer as a memento, to be handed by him to the Royal Institution for placing with Faraday's other specimens now in the ambulatory of that building, and to remain there for all time.

In the same way, he was hoping to be able to place in the Royal Institution a specimen of this similar material melted in the arc radiation furnace by Dr. Benedicks.

AUTHOR'S REPLY.

Professor CARL BENEDICKS replied that he was greatly indebted to Sir Robert Hadfield, Bt., F.R.S., especially in his quality as the author of that most interesting and important book on Faraday and his Metallurgical Researches, for his appreciative remarks concerning the present contribution to the knowledge of the material produced by Faraday. He appreciated his emphasis of the usefulness of the, so-to-say, micro-method for determining electrical resistivity, worked out in Stockholm. The fact that the method required only a small plane surface—like that, or even much smaller than that of any specimen for microscopic examination—actually enabled determinations to be made on specimens otherwise out of reach from an electrical point of view. So, not only specimens of historical value, which were to be left essentially untouched, but also small samples of rare metals could be investigated.

The details referred to regarding Dr. Hales' furnace at Mount Wilson, in which solar radiation was used, were extremely interesting. Before making, with Mr. J. Härdén, the first experiments with the furnace using arc radiation, the author had made an approximate calculation of the effect attainable from the sun. Using data furnished by Dr. A. Ångström, it was found that a lens 40 cm. (16 in.) in dia. (assuming 15% losses in reflection + absorption) would produce as a maximum about 0·09 kW. As an electric arc produced easily, say, 5·0 kW., it was obviously much simpler—or at least required much cheaper equipment—to use electrical energy.[1] This, of course, when suitable means were at hand, did not prevent good results from being obtained with solar radiation. Thus, recently, Mr. W. M. Cohn [2] had used a solar furnace developed by C. Zeiss in Jena, with a 100-in. searchlight mirror (invented by R. Straubel), for melting ZrO_2.

[1] C. Benedicks and J. Härdén, *Zeitschrift für technische Physik*, 1931, vol. 12, p. 234.

[2] *Transactions of the Electrochemical Society*, 1935, vol. 68, p. 65.

SIXTH REPORT ON THE HETEROGENEITY OF STEEL INGOTS.

By a JOINT COMMITTEE of the Iron and Steel Institute and the British Iron and Steel Federation.

This Report, published as Special Report No. 9, was presented for discussion at the Autumn General Meeting of the Iron and Steel Institute, held in Manchester, on September 17, 1935. It was also discussed at Joint Meetings of the Iron and Steel Institute with the following Societies: The Sheffield Society of Engineers and Metallurgists, and the Sheffield Metallurgical Association at Sheffield on November 4, 1935; and the Staffordshire Iron and Steel Institute at Birmingham on November 29, 1935; further contributions to the discussion were received by correspondence.

In order that the Discussion, Correspondence, and Committee's Reply may be available in a compact form, they have been published as Special Report No. 9A, a supplement to Special Report No. 9, which contains the Report itself.

WASTE-HEAT BOILERS IN OPEN-HEARTH PRACTICE.

SECOND REPORT OF THE OPEN-HEARTH COMMITTEE, BEING A COMMITTEE OF THE IRON AND STEEL INDUSTRIAL RESEARCH COUNCIL.

This Report, published as Special Report No. 10, was presented for discussion at the Autumn General Meeting of the Iron and Steel Institute, held in Manchester, on September 18, 1935. It was also discussed at Joint Meetings of the Iron and Steel Institute with the following Societies: The West of Scotland Iron and Steel Institute, at Glasgow, on October 18, 1935; the Sheffield Society of Engineers and Metallurgists and the Sheffield Metallurgical Association, at Sheffield, on November 18, 1935; the South Wales Engineering Society, the South Wales Branch of the Institution of Mechanical Engineers, the South Wales Siemens Steel Association, the Swansea Technical College Metallurgical Society, and the Welsh Plate and Sheet Manufacturers' Association, at Swansea, on December 6, 1935; the Cleveland Institution of Engineers, at Middlesbrough, on January 20, 1936; and the Lincolnshire Iron and Steel Institute, at Scunthorpe, on February 18, 1936. Further contributions to the discussion were received by correspondence.

In order that the Discussion, Correspondence, and Committee's Reply may be available in a compact form, they have been published as Special Report No. 10A, a supplement to Special Report No. 10, which contains the Report on " Waste-Heat Boilers in Open-Hearth Practice " itself.

THE WORK OF THE CORROSION COMMITTEE.

JOINT COMMITTEE OF THE IRON AND STEEL INSTITUTE AND THE BRITISH IRON AND STEEL FEDERATION REPORTING TO THE IRON AND STEEL INDUSTRIAL RESEARCH COUNCIL.

BEING A REVIEW OF THE WORK TO DECEMBER 31, 1935, COMPILED AT THE REQUEST OF THE COMMITTEE.

BY DR. W. H. HATFIELD, F.R.S. (CHAIRMAN).

This review of the work of the Corrosion Committee was published as Special Report No. 11. It covers the various investigations carried out since the formation of the Committee in 1928 to the end of 1935. These included field tests conducted at stations subjected to inland, marine, arctic, temperate, sub-tropical, and tropical conditions; marine observations under practical conditions (including the examination of ships' hulls, tests on ships, and miscellaneous studies); complementary investigations by members of the Committee and other workers—these embrace spray tests, small-scale field tests, studies on the effect of rolling scales, inclusions and other factors influencing corrosion; and various examples of corrosion and longevity reported to, or investigated by the Committee. Finally, an outline of work suggested but not yet proceeded with is presented. Appendices covering the personnel of the Committee, statistical data on the work of the Committee, the dates of exposure of the specimens, and the climates of the corrosion stations supplement the main body of the Report.

THE WORK OF THE HETEROGENEITY OF STEEL INGOTS COMMITTEE.

JOINT COMMITTEE OF THE IRON AND STEEL INSTITUTE AND THE BRITISH IRON AND STEEL FEDERATION REPORTING TO THE IRON AND STEEL INDUSTRIAL RESEARCH COUNCIL.

BEING A REVIEW OF THE WORK TO DATE (DECEMBER 31, 1935) COMPILED AT THE REQUEST OF THE COMMITTEE.

BY DR. W. H. HATFIELD, F.R.S. (CHAIRMAN).

This review was published as Special Report No. 12. It covers the work of the Committee since its inception in May, 1924, and embraces general studies of the nature of heterogeneity (during which sixty-nine ingots were examined), and of the effect of casting temperature on crystallization, and the mechanism of freezing. Short summaries of complementary researches by members of the Committee and other investigators are given; the subject-matter of these researches dealt with the freezing temperatures of commercial steels, non-metallic inclusions, oxygen in steel, nitrogen and other gases in steel, the effect of gases in rimming steel, the density of molten steel, and differential solidification. Other work undertaken included mathematical researches on behalf of the Committee, and investigations on the determination of the temperature of liquid steel and the problem of ingot mould design. There are six appendices, dealing with the personnel of the Committee, an analysis of the six Reports issued during the period under consideration, details of the sixty-nine ingots so far examined and of the ingot moulds investigated, an index of work done, and an index of work in prospect.

ANNUAL DINNER.

THE Annual Dinner of the Iron and Steel Institute was held on Thursday, May 7th, 1936, at the Connaught Rooms, Great Queen Street, W.C.; Sir Harold Carpenter, Ph.D., D.Sc., F.R.S. (President of the Institute), was in the Chair, and the company numbered over five hundred. Those present included The Rt. Hon. A. Duff Cooper, D.S.O., M.P., His Highness Prince Otto von Bismarck, The Rt. Hon. the Viscount Falmouth, The Rt. Hon. the Lord Crawford and Balcarres, P.C., K.T., The Rt. Hon. the Lord Hirst of Witton, The Rt. Hon. the Lord Stonehaven, P.C., G.C.M.G., D.S.O., LL.D., Lieut.-General Sir Hugh J. Elles, K.C.B., K.C.M.G., K.C.V.O., D.S.O. (Master-General of the Ordnance, War Office), Major-General Sir John Headlam, K.B.E., C.B., D.S.O., Mr. B. Talbot, Mr. F. W. Harbord, C.B.E., Sir Andrew R. Duncan (Chairman of the British Iron and Steel Federation), Professor Henry Louis, M.A., D.Sc., Sir Frederick Mills, Bt., D.L., M.P., Sir Harry McGowan, K.B.E., Col. Sir W. Charles Wright, Bt., K.B.E., C.B., Mr. W. R. Lysaght, C.B.E., Sir William Bragg (President of the Royal Society), Mr. John Craig, C.B.E., Sir William Larke, K.B.E., Captain Sir Edward Headlam, C.S.I., C.M.G., D.S.O., R.I.N., Sir Rupert Howorth, K.C.M.G., C.B., C.M.G., Sir Clement Hindley, K.C.I.E., Sir Frederick Minter, K.C.V.O., C.V.O., Dr. O. Petersen (Director of the Verein deutscher Eisenhüttenleute), Mr. W. Benton Jones, Mr. James Henderson (Hon. Treasurer), Mr. Douglas Vickers, J.P., Mr. L. Ennis, Mr. A. C. Macdiarmid, Mr. C. P. Sandberg, C.B.E., Mr. A. Hutchinson, Mr. H. W. Bessemer, Mr. S. R. Beale, Mr. A. K. McCosh (President of the British Iron and Steel Federation), Mr. Cyril E. Lloyd, Mr. H. A. Brassert, Mr. O. F. A. Sandberg, O.B.E., Mr. Arthur Dorman, Mr. I. F. L. Elliot, Mr. John D. Watson (President of the Institution of Civil Engineers), Dr. C. H. Desch, F.R.S., Mr. Herbert N. Gresley, C.B.E., D.Sc. (President of the Institution of Mechanical Engineers), Dr. W. H. Hatfield, F.R.S., Mr. W. R. Barclay (President of the Institute of Metals), Mr. Carl Davis (President of the Institution of Mining and Metallurgy), Mr. T. Westthorpe (President of the Coke Oven Managers' Association), Mr. J. T. Wright (President of the Staffordshire Iron and Steel Institute), Mr. F. Bainbridge (President of the Cleveland Institution of Engineers), Dr. A. McCance, Mr. P. B. Brown, Principal C. A. Edwards, D.Sc., F.R.S., Mr. A. L. Hetherington, Dr. R. Seligman, Dr. H. J. Gough, F.R.S.

The Toasts of "His Majesty The King" and "Her Majesty Queen Mary, Their Royal Highnesses the Duke and Duchess of

York, and the other Members of the Royal Family " were proposed by the President and loyally received.

The Iron and Steel Institute and The Iron and Steel Industries.

The Right Hon. A. Duff Cooper, D.S.O., M.P., Secretary of State for War, proposed the Toast of " The Iron and Steel Institute and the Iron and Steel Industries."

He said: I am singularly ill-equipped to propose such an important toast, and I had better tell you at once that I am quite ignorant both of the Institute and of the Industry. (*Laughter.*) I do not propose—although I have been furnished with material to enable me to do it—to give you facts and figures which you know far better than I do about the activities of the Institute or the state of the industry. I think that the Institute and the industry are wise—although it may seem illogical, as most things in this country do seem—in that on an occasion such as this, instead of inviting someone with deep knowledge and long experience to give them his views and opinions upon the state of the industry and the activities of the Institute, they invite one of that poor, ignorant, and universally-despised class, the politicians, to come here and talk to them about anything that he likes. (*Laughter.*) I sometimes think that the day will come when the politicians of this country will have to get together with the Untouchables of our Great Indian Empire, as being the only two sections of large communities which are universally despised. (*Laughter.*) But, when we are asked out into respectable company and given a good meal and allowed to speak our minds, I am sure you will forgive us if we take every advantage of such an occasion to air our views, for what they may be worth. (*Laughter.*)

I have said that I know very little about the Institute and the industry, but I do know sufficient about both to feel that I am performing nothing less than a public duty when I propose their health, because you know that a politician never says anything or proposes any toast or supports any proposal in which he does not sincerely believe. (*Laughter.*)

I believe that the industry is of great value to this country. In the first place, it produces wealth and it gives employment, and in the second place it provides us with the means—and can and will and must provide us with the means—of defending ourselves, should the catastrophe ever occur of our having to defend ourselves against an aggressor. I know also that the Institute performs a tremendous service, because it encourages what we now realise that industry cannot get on without, and that is research, scientific inquiry into how our industry can best be improved and how it

can equip itself properly to compete with the industries which are competing against it all over the world.

We had a great start in the industrial competition of the nineteenth century. Conditions, which I will not go into now, favoured us, and we took full advantage of those conditions. One of our great enemies once referred to us contemptuously as a nation of shopkeepers. We never resented that appellation, because Englishmen are not ashamed of keeping shop; after all, what is a shopkeeper but a man who provides, for comparatively small remuneration, what other people require? He is one of the most useful members of the community.

But it was after Napoleon was dead, rather than when he was alive, that we really entered into the full glory of our shopkeeping. In his day we were a small shop in a side street, but after his death we became the largest emporium in the world, and we really did at one moment provide all the world with nearly everything that it required. Unfortunately, as all business men are aware, as soon as somebody starts making a fortune in one direction, other people wake up to the fact that there is money in it, and now those who were our customers, and our best customers, have become our keenest competitors; and we have realised that we can only keep pace with this competition, we can only hold our position in the world of industry and of commerce, by producing something better, by producing something more rapidly, by producing something more cheaply, than all the best brains and most skilful workers in other countries can produce for the same market. Faced with this new challenge, we have turned—and not too late, I hope—for assistance to science and to this Institute. This Institute, which we are here to celebrate to-night, is doing that invaluable, inevitable and most important of all work, encouraging research for the development of industry, publishing the results of research work and assisting research by the creation of many committees to deal with the subject.

It seems to me that if, as we all hope, peaceful conditions prevail in the world, the great struggle of the future is going to be a struggle in industrial efficiency. In the world of the future, particularly if it is a peaceful world, it is the most efficient who will survive, and therefore upon education and upon research no money that is spent can be mis-spent, no money that is invested can be better invested; because to the nation who produces the best at the lowest price belongs the future industrial control of the world.

But there is another reason why I occupy the position that I do to-day. I am glad to be present this evening and to pay my tribute to the Iron and Steel Institute and to the Industry. There is a fearful possibility that the peaceful conditions to which I have referred may not prevail; there is a fearful possibility that we may once more be plunged into the horrors of war, a war infinitely more horrible than any that has preceded it. There have been various

ways in which the nation and the statesmen have considered that we ought to guard against this danger. There have been people who believe that it would be a good thing to set an example by throwing away our weapons. That has been an example which we have set; no country has gone so far in voluntary, unilateral disarmament as our own. Many people think that we have gone too far; many people think that we have incurred too great risks by assuming too soon that the danger would not occur again, by hoping too optimistically that an example set would be followed. It is easy to-day to blame those who during the last seventeen years have had responsibility for the position in which we find ourselves at the present time. It is very easy to be wise after the event; it is easy for those who have not been engaged in the extremely difficult and delicate profession of politics to say that we never should have reduced the estimates for the Defence Services.

There are two replies to those who say that. The first is that no one who has had to take his part in the hurly-burly of political life during those seventeen years, who has had to submit himself to an electorate, who has had to argue his case upon a platform, who has had to rely for his position on a popular vote, could have taken that attitude. It is easy for someone who has never had to do that to say that every step that has been taken has been wrong, but I can assure you that there would have been little hope for any Parliamentary candidate, except in the safest of safe seats, who during the last seventeen years, while the Disarmament Conference was in session and the whole world was calling for disarmament, had got up on a platform and said that we ought to increase the money that we are spending on the Army and Navy. That is a difficulty which may not have been present to your minds, but it was present to the mind of every candidate who stood for the House of Commons; if he had taken that line he would have received a knock-out blow in the first round; that difficulty was always present as a fist in front of his face.

But there is another answer to those who say that we have gone too far and that we have allowed our Services to slip into too great a measure of unpreparedness, and it is this. There was a hope that this new scheme of world control by a central body meeting at a central place, a body of civilised Powers all desiring peace, might be able to produce a state of affairs which would prevent this fearful menace, a menace which, as those engaged in business before the war knew, was a menace which hung over their affairs and made them difficult to conduct. There was a hope, as I say, that that menace might be removed. If that had been possible, if it had been possible to create a world where there was no danger of war between great civilised nations, was not it worth while taking almost any risk to achieve that end? Personally, I think that it was; and I am not ashamed but proud of the various British Governments which held office from 1918 to 1934, and which

were prepared to stake everything upon that card, because if that card had proved a winner it would have marked a new era in human affairs and the beginning of a new and better world. (*Applause.*)

Well, that card has not won. It was an outside chance and worth backing, but it has failed, and now, at long last—but, as we all hope and pray, not too late—this country has determined to equip itself once more to take its part in the counsels of the nations of the world, not only with a firm and strong voice on the side of peace but also with a strong arm behind it that will enforce its counsels and lend them authority.

It is a tremendous task which faces the present Government. Do not let us minimise it. We have four years, or perhaps four and a half years, of office in which to accomplish it. Pray God we also have four and a half years of peace. We have now to re-equip ourselves and to make sure that our interests, which are bound up with peace, shall prevail, and that any possible menacer of peace, if such exists, shall hesitate before encountering the disapproval of so powerful an Empire.

Now, in that task that we have to perform in so short a period we want the help of the whole community, but there is no section of the community whose help we want so much, and upon whose assistance we must rely so closely, as the industrial community. Industry has always been the backbone of the country. We are an industrial nation; upon industry our wealth, our power, our prosperity, and our glory have been founded. For the assistance of industry we now appeal in the enormous task that lies before us. We appeal to industry with confidence, because we know that in industry, and above all in the iron and steel industry, we have some of the best brains in the country at the head of some of the finest skilled workmen in the world. There has been talk of over-population and of over-production, but we can never have too much patriotism, too much intelligence, too much skilled labour.

You represent an industry which has always been a pioneer in world affairs, because, although other iron and steel industries may now be competing, may now be inventing, may now be catching up and may now have caught up with all that we have done, there can be no doubt that the British iron and steel industry has led the van in scientific development, in scientific research, and in industrial progress. Upon you there is now the great responsibility of giving us all the assistance at your command. We have no fears; we have not the slightest hesitation in making our appeal to your great industry, because we know that it is solid to the core, we know that it is sound, we know that it is intelligent, we know that it is highly developed, and we know that, given the encouragement and assistance that it deserves, it will beat the industry of any other country in the world.

I ask you to reflect, however, upon the responsibilities that lie upon this great industry in the year that lies before us. There is

a great menace threatening our civilisation, the cloud of a possible war. The Prime Minister has said that if that cloud ever bursts not the British Empire alone but our whole civilisation will disappear, as the civilisation of Rome did before the Dark Ages. But the bursting of that cloud may be prevented, and I believe that the surest way of preventing it from bursting is by presenting to the world a British Empire devoted to peace and so strong that no one will willingly incur its disapproval. (*Applause.*)

That is why it gives me so much pleasure to be here this evening and to propose the toast of your Industry and your Institute, and to couple with it the name of your President, Sir Harold Carpenter, who has done so much for both the industry and the Institute and who has been ready, as members of your industry have always been ready, to lend his services to the State, and who has served recently on a Committee dealing with the position of scientific officers serving in the various departments of the State. There has always been a readiness to co-operate between industry, the Civil Service and the Defence Services in this country, proving the fact, which it is very important that the world should realise, that we are one united nation, that industry serves the State and the State supports industry, and that the Civil Service is merely another branch of those who would serve industry to promote the wellbeing of the country, that we are one people with one purpose, and that purpose is peace—peace, which we must be strong enough to defend. (*Applause.*)

THE PRESIDENT (Sir HAROLD CARPENTER, F.R.S.), who responded on behalf of the Institute, said: I must begin by saying how much we of the Institute appreciate the fact that Mr. Duff Cooper has been able to accept our invitation to dine with us this evening, and that we welcome him not merely for himself, as Mr. Duff Cooper, but also on account of the position of very great responsibility which he occupies as Secretary of State for War, and, last but not least, as the author of that remarkable study, "The Life of the late Lord Haig." We laid upon him the task of proposing the Toast of the Institute and the Industry. I am very pleased that the task of responding for the Industry will be discharged by my old friend Sir William Larke, with whom I have engaged on many scientific and industrial research quests in the past.

I am sure we have all listened with deep interest and pleasure to the delightful speech which Mr. Duff Cooper has made.

Our membership roll to-day no longer contains a name which until last December had been there for sixty years, a name which to-day is almost forgotten, that of Percy Carlyle Gilchrist. His latter years were clouded by ill-health, and many people, I think, did not even realise that he was alive; but there was a period when his name rang through the steel industry of this country,

for he was, with Thomas, the originator and inventor of what is known as the basic process of steel manufacture. It is difficult to realise that in him we had a living link with the creators of cheap steel and the modern steel industry. If I may put it in another way, mankind has used steel for at least three thousand years, but it has been plentiful only in the last sixty. Bessemer and Mushet, Thomas and Gilchrist were the four creators of that industry, and it seems to me that I may fittingly take this opportunity, for it will not recur, of telling you briefly the history of the two great discoveries which led to its foundation, for I do not think it is at all generally known.

The first scene opens at a French artillery practice ground near Paris. Henry Bessemer, an inventor but not a metallurgist, who had failed to arouse the interest of the War Office in an invention for a rotating projectile, had succeeded in enlisting the interest, and not only the interest but the financial support, of Louis Napoleon. He was over on this practice ground witnessing the trials of his invention, and a French Commandant, Commandant Minie, said, in effect, "This invention of yours will require a better gun than a cast-iron gun." And so Bessemer returned to England to make a gun that would not burst on firing. At that time not only the gun, but also the projectiles were made of cast iron.

He set to work not two miles from this hall and did some experiments at a foundry in St. Pancras. He must have been a wonderful man, because although he was not a trained chemist or physicist he had the root of what we call thermo-chemistry and thermo-metallurgy in him, and after a very few experiments he conceived the original idea of removing the impurities from molten cast iron by blowing air through it without external heat. In less than a month he had carried out his experiments successfully, and he erected his well-known converter, which was simply an iron shell with a refractory lining and with tuyeres through which the air was introduced. The only difficulty he had in the experiment was with his assistant, who thought that he was quite mad! He made him pour the cast from the cupola into the converter, and started to blow air through it. No one knew what would happen, and at first nothing much did happen; the reaction was quiet at first, but then it became violent and nearly set the place on fire. In the end the converter was tapped out into a mould, and Bessemer obtained an ingot of malleable iron. That was the first cast of what is to-day called mild steel. He had, within half an hour, raised the temperature of a mass of fluid pig iron several hundred degrees and removed the greater part of the impurities without the use of any fuel.

He showed a similar experiment to his friend George Rennie, and, following Rennie's advice, he went the following week to a meeting of the British Association at Cheltenham to report his discovery. Certain rumours of his discovery had got about, but

those who came to scoff remained to be convinced, and the reception by the British Association was of the very best. Not only that, but a Welsh iron-maker, Mr. Budd, offered to try the process at once.

But, to use a modern expression, Bessemer had "got away with it" rather too easily. Quite by chance he had used one of the few suitable brands of low-phosphorus pig iron made in this country, and that is why his first experiment was successful. Then things began to go wrong. At that time there was no such thing as the chemical control of cast iron, and various iron-makers set to work to repeat this process, using their own brands, not knowing that what was right for the refinery or puddling furnace was wrong for converters lined with siliceous materials. Almost without exception the irons produced were worthless, since they were quite brittle. This brought about a complete reaction against the process, which was denounced as the dream of a wild enthusiast such as a sensible man could not for a moment have entertained.

There was no Iron and Steel Institute in those days, and Bessemer had to fight his difficulties by himself. For eighteen months he worked to try to remove the phosphorus from the cast iron, but without success. He finally showed, however, that it was the phosphorus which was responsible for the difficulty by sending to Sweden for pure Swedish non-phosphoric pig iron, and, using this for his charge, he was able to convert it into pure, soft and malleable iron, and also into steel of various degrees of hardness every time.

By now, however, the process was discredited and nobody would take it up, so that Bessemer was forced to become a steel-maker himself. He was that unusual combination, an inventor and a good business man. He went into partnership with four other men, and that partnership lasted for fourteen years. Their works were at Sheffield, and during those fourteen years they made eighty-one times their capital, or an average of nearly cent per cent. every two months. Bessemer had solved the problem of making steel without fuel from low-phosphorus iron, but the majority of ores in this country, of course, contain too much phosphorus.

In 1869 the Iron and Steel Institute was founded, and you will see that it had an important influence on the second discovery. The second scene opens in a lecture-room in the Birkbeck Institute, where an evening student is listening to a lecture on cast iron, and he hears the sentence "The man who eliminates phosphorus by means of the Bessemer converter will make his fortune." The student was then a junior clerk in the Metropolitan Police force, at a salary of £90 a year—Sidney Gilchrist Thomas. That remark lit the flame of desire to solve the problem in Thomas's mind. He began experiments in his own house, in the chimney of his little attic, and he then enlisted the help of his cousin, Percy Carlyle Gilchrist, who was the chemist at an ironworks at Cwmavon in South Wales. These two men worked all their spare time on the problem, on entirely different lines from those of Bessemer, and in

the end they took out two patents. But by this time they had exhausted almost all their resources; they were not men with financial resources behind them, and they had not been able to try out a large-scale experiment. However, Mr. Martin, the General Manager of the Blaenavon Steel Company in South Wales, came to their assistance, and further experiments were made, and finally a third patent was taken out in 1878. Following upon that, they presented a paper to this Institute at its Autumn Meeting that year in Paris, entitled "On the Elimination of Phosphorus in the Bessemer Converter." So little was its importance realised that it was not read, but was adjourned until the meeting of 1879. The action of the Council in not putting the paper on the list of papers to be read has been condemned, but I should not be prepared to say anything until I knew the reasons which actuated them. Whatever their intention, however, the result was fortunate, because it enabled Thomas and Gilchrist to come in touch with Mr. Windsor Richards, of Bolckow Vaughan and Company, who had the resources to enable the process to be tried. The personality of Thomas in particular greatly impressed him. Accordingly, arrangements were made for a phosphoric charge to be blown, and the first successful charge was blown in April 1879. There were three essential conditions to be satisfied. It was necessary to line the converter with the basic material, not merely of the correct composition, but also of the requisite temperature-stability, so that its adhesion to the converter walls during the blow was maintained. Secondly, it was necessary to form a rich basic slag at an early stage of the process. Thirdly, it was found that while carbon, silicon, and manganese were removed at an early stage of the blow, the phosphorus was not sensibly diminished until later. This necessitated the so-called "after blow," during which about 80% of the phosphorus thus removed is eliminated.

The experiment having been successful, at the May Meeting of the Institute in 1879 Thomas and Gilchrist read their paper. The position had changed since Bessemer's discovery, and they had been able to obtain the assistance of members of the Institute to help them to solve their problem. This great discovery rendered available those irons which contained too much phosphorus for the acid process. In one respect it may be said that this is even more important than the original acid Bessemer process. In the latter the ferruginous slag is a waste product, but in Thomas and Gilchrist's process the slag is an important agricultural fertiliser, and therefore both products are used.

I think we may well be proud of the fact that these two great discoveries, which really laid the foundations of and created the modern steel industry, were made by men of this country; and I should like to say in conclusion that I think it is particularly appropriate that Henry Bessemer, a grandson of the original Henry Bessemer, is dining with us this evening. (*Applause.*)

Sir WILLIAM LARKE, K.B.E. (Vice-President), who responded for the Industry, said: It is indeed a privilege and a responsibility to reply on behalf of the Industry to the eloquent address that we have had from the Secretary of State for War. I feel disposed, if I may, in a sentence or two to confirm the impression which he thinks industrialists have of politicians. (*Laughter.*) I remember too well that dreadful period from 1921 to 1931, the black decade, during which I struggled, with you, in the morass of depression. During that time it was my lot to be your spokesman and to endeavour to represent the plight of the industry to the politicians of those days; and, irrespective of party, they were indeed untouchable! (*Laughter and applause.*) I like to think that they had some confidence in our *bona fides*, but they evidently then had none in my judgment; I never succeeded in inducing them to take any measure that would foster the recovery of the industry. There was, indeed, one school of political thought which said "Your nostrums are objectionable and nonsensical, and if you and your industry were not such fools you would not have to ask for them to be applied." (*Laughter.*) In justice to those who took that view, let me say that since events have falsified their opinions they have, as sportsmen, confessed that they were wrong.

It has been well said that it is the business of industries to govern themselves, and it is the duty of the State to create the conditions in which the efficient self-government of industry becomes possible. In 1931 the politicians faced a situation in which, bankrupt in policy, they went to the country, and said "United we stand, divided we fall; put us into office and we shall do the best we can to deal with the situation as it arises in any manner that we think fit." (*Laughter.*) It was then, and only then, after this dark period that I began to see a ray of hope. When the National Government was returned, it made good its claim for a doctor's mandate. It applied a policy of protection; it created the conditions in which the efficient self-government of industry became possible.

And now, perhaps, I may say a brief word as to how this industry has endeavoured to take advantage of the conditions that were thus created. At any rate we were able to refute the criticism, so often made before 1931, that we did not know our business. We were able to make good every claim we had made to the politicians before 1931 as to what we should be able to do if they would create the necessary conditions to enable us to do it. We are grateful to the Government of 1931 and that which has followed it. We are glad to think that co-operation between this industry and the National Government has been so close and so efficacious. One of the best measures taken by that Government was the appointment of the Import Duties Advisory Committee. Speaking with some knowledge of the tariff organisation of nearly every country in the Empire and throughout the world, let me say that the organisation

which this Government has set up for dealing with tariff problems is unequalled elsewhere in the world, both in the simplicity of its procedure and in the impartiality of its consideration. There is no body of a like character in any country in the world which even approaches it. We must remember, moreover, that in the space of a few short weeks this country reversed a fiscal policy which it had favoured for eighty years, and yet our Customs department was able to cope with that reversal of policy without a hitch and, so far as I can learn, without any delay. That, you will agree, was a remarkable feat. (*Applause.*) We in the industry owe a debt of gratitude not only to the Ministers who accepted the responsibility, but to the public service which was able to carry out that policy so effectively. (*Applause.*)

Now as to the position in which the industry finds itself. Mr. Duff Cooper mentioned, among other attributes of our industry, that it produces wealth. Well, to that we have been strangers for nearly a generation. (*Laughter.*) There are signs that we may once again produce wealth, but we have to make up the leeway lost during fifteen years or more during which it is amazing that the industry survived.

He also said that we give employment. With regard to employment, we are humbly thankful and proud that since 1933, when our unemployment figures were high, amounting to 41% of insured workers in the industry, they have been going down, until at 31st March last they were only 20%, and they are still being reduced.

We have heard something lately about co-operation, national, international, and industrial. I have paid a tribute to the co-operation between the Government and industry. The idea is too prevalent to-day that co-operation means that everyone else must agree with our own views, and then we are ready to co-operate. We have indeed, however, established a great measure of co-operation within the iron and steel industry, and I think that we are entitled to take some credit for it; but the form of co-operation to which I have referred is not altogether absent from our councils. If I may lift the veil for a moment, I think it is time that we remembered that co-operation means collective action for our mutual benefit, and that if we are to establish co-operation we must be ready to give up something of our own views, in order that we may induce others to give up something of theirs and so that we may meet on common ground.

It was said by Andrew Carnegie that the iron and steel industry was always either prince or pauper. That may have been true, but I think it was a reflection on its management. There is no advantage in being a vagabond king for a night and a pauper for the rest of one's life. We have often been kings for a very short time and too often paupers for a very long one. We have now reached a position where we must choose between mere opportunism

and statesmanship. Opportunism is easy; it is exploiting the advantage of the moment and thus sacrificing the permanent security of the future. Statesmanship is much more difficult, for it involves restraint and sacrifice and caution. We must always keep before us the necessity of stimulating our consumers to consume, and therefore in the adjustment of the price structure which must follow the emergence from depression into industrial activity we must bear that essential fact in mind and see that our price structure is such that we do not destroy the recovery we are enjoying and do not prevent ourselves from converting it into a condition of permanent prosperity. (*Applause.*)

I have detained you long enough, but I want to say this in answer to the Secretary of State for War. There are many of us who served in positions in which we had something to do with the organisation of industry for war purposes and the relation of industry to the needs of the State. During the four years of the late war this industry increased its capacity by no less than 50%, and it emerged from the war crippled in its financial resources, because in the aftermath of the war it was left with a capital commitment which it had incurred to serve national needs, for which there was no peace-time employment, and it thus had to carry an undue proportion of the national debt. I mention that for this reason, that I believe that that mistake was a substantial contributing factor to the industrial depression in this country, and we must try to avoid making such a mistake should such conditions unhappily arise in the future. But in answer to the invitation of the Secretary of State for War, I know that I can say without hesitation that, whatever the needs of the State may be, whatever the needs of the great Services may be, this industry will undertake to supply them at whatever sacrifice it may mean. (*Applause.*)

The Visitors.

Mr. John Craig, C.B.E., J.P. (Vice-President), who proposed the toast of "The Visitors," said: There are some duties in life the importance of which can be measured by their difficulty of performance, but I am happy to think that, although I have been entrusted with an important duty to-night, it cannot be measured by any difficulty there is in its performance, for I am satisfied that it requires no words of mine to ensure that the toast which I have to propose will have a most cordial and enthusiastic reception by the members of the Institute. The toast as given to me was "Our Guests," but on the printed list it appears as "The Visitors." I do not know whether there is some subtle distinction! (*Laughter.*)

So far as we members of the Institute are concerned, we seem always to be very happy and very rich in our friends. I had occasion years ago to propose a similar toast, when we were very deeply in the depression, and all that was left to us as an industry

was our friends, for there was not much in the industry itself. (*Laughter.*) To-night we are in a happier position, for, in addition to being equally rich in friends, our industry is once again occupying a position of some importance. Ten years ago, and indeed throughout the period referred to by Sir William Larke, it seemed as though there were no place for our industry in this great country. We were neglected by the authorities, and we were also, I think, neglected by all those concerned with finance; nobody was inclined to put any money into the industry.

I think that those days are gone, and it seems now that our industry will be able once again to play its part in the history of the development of our country.

Perhaps the most effective way of proposing this toast would be simply to read out a list of our visitors to-night, adding a comment or two as to the great places which they occupy in the Government, in scientific and engineering societies and in our great industries. That, I think, would be a very impressive way of ensuring your enthusiasm. I am not going, however, to attempt a catalogue of our great host of guests, but I am sure we all wish to express our high appreciation of having a member of the Government with us to-night. (*Applause.*) The relations of our industry with the Government of the country are closer than hitherto, and we can undoubtedly say that we have a higher appreciation of them now than we had before.

I should like to pay a tribute to our guests from the Civil Service. I do not know whether I may describe them as a great arm of the Government; I think they are entitled to be described as a limb, as something even more important than an arm, because our Civil Servants perform the very highest service to the country as a whole. (*Applause.*) As we come in contact with them more freely, so we recognise better the great debt which we owe this magnificent Civil Service. We are also very pleased to have with us distinguished officers from the Services. They, like ourselves, are coming more into the limelight in these days. We realise how fortunate the country is in having men of such marked ability at its disposal in all times of difficulty, and we honour the members of the Services who are our guests to-night.

I would likewise welcome on your behalf the heads of the great scientific societies. The members of these societies do much of the "advance thinking" for our industry, as well as putting at our disposal secrets drawn from nature of which they enable us to make commercial use. We value their great service, because in it lies the hope for the prosperity of our great industry. We also welcome most cordially the heads of the great engineering societies whom we have with us to-night. We recognise the engineer as a man who is thinking ahead of us, and who, we hope, is finding uses for our products which will make our industry even more prosperous in the days to come. We have also our friends from kindred

societies, who, like ourselves, are seeking to advance the interests of this country and the good of humanity.

There are others amongst our distinguished guests who are the heads of great companies and corporations. We think of them in a kindly way because they utilise our products and provide us with other products with which we hope to increase the efficiency of our industry as a whole. I notice that the chairmen of some of the big steel companies are classed as visitors and are amongst our guests. I am told by the Secretary that they are so described because they are not enrolled as members of the Institute. I hope that in the future they will not appear as guests, but as members.

I have to couple with this toast the name of a distinguished servant of the State, and one who has been associated very intimately with our own industry, Lord Crawford. (*Applause.*) I have the greatest pleasure in submitting the toast of our Guests, or our Visitors, or both (*laughter*), coupled with the name of the Right Hon. the Earl of Crawford and Balcarres. (*Applause.*)

The Right Hon. THE EARL OF CRAWFORD AND BALCARRES, P.C., K.T., who responded, said: On behalf of the guests this evening, I beg to return very cordial thanks. I have had messages from every quarter of the room expressing appreciation of your hospitality. Some praise the music and some praise the menu; and in connection with the menu I cannot do better than give you a message which has reached me from Mr. H. A. Brassert, who considers that the menu is the best example of rationalised production that he has seen for a long time. (*Laughter.*) He says that there is no overlapping in it, that the equipment is all up-to-date, that there is a very suitable variety of product, and that, so far as the guests are concerned, there are no overhead charges. (*Laughter.*) He is pleased that throughout there has been a correct percentage of liquid assets. (*Loud laughter.*) I hope you will endorse that opinion.

The menu is, of course, very important, but a few days ago, when sending me the draft of my speech (*laughter*), Sir Harold Carpenter said that the men you sit next to are more important than the menu, and he said, "We have a very strong combination in Duff, Cooper, Larke, Craig and Company." (*Laughter.*) I happened to meet Mr. John E. James, and I knew him well enough to say, "Who are Messrs. Duff, Cooper, Larke, Craig and Company?" and he replied, "There is no such firm in the steel trade." (*Laughter.*) I said, "What about Sir Harold's remark?" and he replied, "Well, it's just possible that they may be some new fancy make-up in the Thames Valley of that name." I said, "Is there an element of guesswork in what you are telling me?" and he said, "You remind me of a story of a schoolboy who was asked what he knew of another combination called Dan and Beersheba, and who replied that they were a married couple in the Old Testament, just like Sodom and

Gomorrah." (*Laughter.*) You will acknowledge that Mr. James did not help me much ! (*Laughter.*) Since then, however, I have found out about the firm, and I can tell you that Mr. Duff Cooper is my own Member of Parliament, or at least he would be if they allowed me to have a vote. (*Laughter.*) He considers me as his constituent, at any rate, and he has been very civil to me all the evening. He assures me that he has enjoyed the company very much, also the speeches, and particularly that delivered by the War Secretary. (*Laughter.*)

Just one more message. The name is illegible. I think it is "Craggs," but Sir Andrew Duncan says it is "Montmorency," and Sir William Bragg says it is "Delafee." At any rate, this gentleman himself says, "I am the grandson of Stokes, of Stokes's Law." (*Laughter.*) You spoil the story, gentlemen, if you laugh, because he says, "I rejoice that this has not been made an occasion for frivolous or ribald joking about my grandfather (*laughter*) and in this connection, please ask Sir Harold how to make cent per cent. every two months." (*Laughter.*)

You see, therefore, that from all quarters of the room there is a very warm appreciation of your friendly hospitality. We are indeed grateful that your great industry has passed successfully through a period, and a long period, of vicissitude, facing its problems with initiative, with resource, and above all with courage. Your guests hope that you are now emerging to a happier and more genial situation. From the bottom of my heart I wish success to the Institute and continuing prosperity to your great industry. (*Applause.*)

The proceedings then terminated.

SECTION II.

A SURVEY OF LITERATURE ON THE MANUFACTURE AND PROPERTIES OF IRON AND STEEL, AND KINDRED SUBJECTS.

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The Editor has been assisted in the preparation of this Survey by R. Elsdon, Librarian of the Institute.

SECTION II.

SURVEY OF LITERATURE ON THE MANUFACTURE AND PROPERTIES OF IRON AND STEEL AND KINDRED SUBJECTS.

Editorial assistance has been given by R. Elsdon, Librarian, in the preparation of this Section.

ORES—MINING AND TREATMENT

Method of Scraping in the Lorraine Iron Mines. G. Nouvelot. (Revue de l'Industrie Minérale, Mémoires, 1935, No. 356, Oct. 15, pp. 479–498). The author describes the method of using scrapers employed in the Lorraine mines for moving the ore underground and loading it into the tubs.

New Data on the Compressed-Air Roasting of Siegerland Spathic Iron Ore. H. Gleichmann. (Stahl und Eisen, 1935, vol. 55, Oct. 31, pp. 1164–1165). The author touches on difficulties previously encountered in roasting the ore in a compressed-air furnace, indicates the improvements introduced into the furnace, and notes briefly the better operating results so obtained. The roasting furnace is of the Strecker type, and is installed at the Neue Haardt Mine of the Vereinigte Stahlwerke, A.-G.

Sintering of Flue Dust and Fine Ore in the Shaft Furnace. J. W. Gilles. (Stahl und Eisen, 1935, vol. 55, Nov. 7, pp. 1188–1190). Details are first given of A. Daub's patent shaft sintering furnace; the mode of filling and its influence on the sintering process, and the blowing procedure are described. Results obtained with an experimental plant on the sintering of blast-furnace flue dust and raw fine spathic iron ore are recorded. The output of the furnace can be increased, but the author recommends rather the use of a larger number of smaller furnaces. The process enables smaller works to work up fine ores on the spot.

Sintering Adds Greatly to Efficiency of Ironton (Utah) Plant, Columbia Steel Co. G. D. Ramsay. (Mining and Metallurgy, 1935, vol. 16, Sept., pp. 365–368). At the Ironton blast-furnace works it was discovered that by sizing the ore—and principally by reducing the size of the coarsest pieces—the efficiency of the blast-furnace was improved and the consumption of coke decreased. At the same time, however, the proportion of fines in the charge rose, leading to difficulties on that account. To obviate this, sintering was adopted. Two straight-line Dwight-Lloyd machines were installed to deal with the fine ore, flue dust, and manganese tailing from flotated ore. Modifications were made to the sintering machine (originally used in a copper smelter) to increase the thickness of the bed, the width of opening of the ignition furnace, and the capacity of the suction fans. At present the sinter is not crushed before going to the blast-furnace, although this is contemplated. The performance of the sintering plant has exceeded expectations, a marked decrease in the fuel consumption being obtained, together with a diminution in the amount of flue-dust produced.

REFRACTORY MATERIALS

Alkalies and Refractory Materials. F. H. Clews and A. T. Green. (Transactions of the Ceramic Society, 1935, vol. 34, Oct., pp. 425–435). The authors commence by discussing the effect of the alkali content on the refractoriness of clays. They point out that although small percentages of alkali may assist in the vitrification of the fireclay products, anything beyond this is likely to lower the refractoriness. Similar considerations apply to the action of alkalies in the solid, liquid, or gaseous states on refractories to which they have access. The action of salt from salty coals in coke-oven practice, the process of salt glazing, the effect of alkalies on the flaking of vertical retort refractories, and the action of alkali salts on the linings of blast-furnaces are among the examples adduced. Finally, the state of the present knowledge on the volatilisation of alkalies is reviewed.

The Action of Alkalies on Refractory Materials. Part I.—The Action of Potash Vapour on Refractory Materials at 900° C. and 1000° C. F. H. Clews, A. Green, and A. T. Green. (Transactions of the Ceramic Society, 1935, vol. 34, Oct., pp. 436–455). Test-pieces of four types of refractory material—an aluminous fireclay, a normal fireclay, a siliceous fireclay, and a silica refractory—were exposed to the action of potash vapour at 900° and 1000° C. The aluminous material at 900° C. absorbed potash most readily, becoming at the same time mechanically disintegrated. On the other fireclay products a protective coating of viscous silicate appeared to form; in the case of the silica brick, however, a fluid silicate was formed which dripped off the test-piece and thus afforded no protection. The extent to which chemical decomposition had occurred was measured by treating the specimens with dilute hydrochloric acid and weighing the undecomposed residue. With up to 55 hours' exposure to the potash vapour the aluminous material was affected the most. The rate of volatilisation of potash from the refractories impregnated with potash solution was ascertained for potash contents varying up to 4% K_2O. The loss of potash from silica was much more rapid than from fireclay products. Preliminary heating for 5 hr. at 1200° C. led to a negligible loss of potash from fireclay on heating to 1000° C. Silica brick treated in the same way lost potash much more readily than impregnated fireclay which had not been subjected to preliminary heating.

Experiments on the Grading, Porosity, and Permeability to Air of Silica Bricks. F. H. Clews and A. T. Green. (Transactions of the Ceramic Society, 1935, vol. 34, Nov., pp. 457–466). Based on the results of preliminary experiments on ground ganister,

silica brick batches have been prepared with a view to obtaining fired products of approximately minimum porosity and permeability. Coarse-, medium-, and fine-grained specimens have been made. The making pressure has been found to affect the permeability to air considerably, but specimens made at $2\frac{1}{4}$ tons per sq. in. were not markedly less permeable than hand-tamped specimens. The effect of the making pressure on the observed apparent porosity was, in comparison with the effect on the permeability, less marked. A further instance has been obtained of the effect on the properties of the fired bricks of the size distribution in ganister classed as fine. Coarse- and medium-grained products of low and almost equal permeability have been obtained, but with a difference in apparent porosity of about 4%. The addition of 0·5% of cellulose liquor tends to produce a material of slightly lower permeability.

Refractoriness and its Determination. F. H. Clews and A. T. Green. (Transactions of the Ceramic Society, 1935, vol. 34, Nov., pp. 467–499). Refractoriness may be considered to be the ability of a ceramic material to withstand high temperatures without loss of rigidity. The authors discuss this property and the various methods of measuring it. They show that a number of factors—such as heterogeneity, chemical complexity, high viscosity, wide melting range, grain size, &c.—operate to render the determination of refractoriness uncertain and somewhat arbitrary. At the same time, methods are available which permit at least a relative assessment; these are described. Pyrometric cones of the Seger and Orton types are often adopted, but the results are influenced by the rate of heating and the mode of preparation of the test-piece; the authors compare American, German, and British practice in this respect, and also touch on certain variants of the squatting test (the signs of fusion test, and the refractoriness safety test). The refractoriness-under-load test is next considered. After discussing the nature of deformation under load at high temperatures, the authors examine American and German methods of carrying out the test, with respect to the temperature used, the type of test-piece, and the method of loading. Certain experimental considerations are dealt with at greater length; they embrace the location of the specimen in the sample of brick, the size and shape of the test-piece, the rate of rise of temperature, and the load. Some of the experimental difficulties met with—including the measurement of temperature, uniform heating of the specimen, the effect of shrinkage, the influence of the expansion of the supports and thrust column, the nature of the furnace atmosphere—are discussed in further detail; the paper concludes with a note on the relation between specifications and the under-load test.

The Effect of the Water Content of Silica Brick Batches on the Porosity of the Fired Brick. T. R. Lynam and W. J. Rees. (Transactions of the Ceramic Society, 1935, vol. 34, Nov., pp. 500–506). Some results of experiments on silica bricks of different moisture

contents are reported. Preliminary experiments were run on briquettes made in the laboratory, in the mixing of which moisture contents above, below, and approximately equal to those normally present were employed. Subsequent experiments were performed on bricks dried and fired under works conditions. Curves in which the moisture contents are plotted against the porosity are reproduced. From the results it is evident that moisture has a considerable influence on the porosity of silica bricks. The tests made under commercial conditions indicate that the porosity decreases with a diminishing moisture content.

Specialised Electric Furnace Refractories. J. A. King. (Metal Progress, 1935, vol. 28, Oct., pp. 27–31). This article treats of those refractories—silicon carbide, aluminium oxide, fused aluminium silicate—which are produced in the electric furnace. Silicon carbide is made by fusing coke, sand, and salt (to remove impurities) in a graphite-cored electric furnace, at a temperature of about 4000° F. The crystals of silicon carbide are crushed, bonded, dried, and fired at 2675° F. Compared with fireclay the chief advantages of this material are its high thermal conductivity (about twelve times that of fireclay), its high resistance to abrasion, and its freedom from spalling. Silicon carbide refractories are on this account particularly suitable for muffle furnaces. A further application is in the sphere of radiant chamber heating, in which the gases are burnt in a combustion chamber before being admitted to the adjacent work chamber. Fused alumina is made from highly purified alumina, and is widely used in electric furnaces owing to its high dielectric strength. Silicon carbide is the basis of many high-temperature cements. High-temperature insulating bricks will not usually withstand flame impingement; if, however, they are coated with silicon carbide cement, they resist the action of flame quite satisfactorily.

Effect of Insulation on the Silica Refractories of an Open-Hearth Steel Furnace Roof. L. B. Miller. (Bulletin of the American Ceramic Society, 1935, vol. 14, Nov., pp. 359–364). The use of insulation on an open-hearth furnace roof is desirable because of the reduction in the heat losses and the savings thus made possible. The determining factor, however, is of a ceramic nature; it is the ability of the refractory to withstand the severe conditions imposed. The factors affecting the life and stability of the refractory roof have been analysed and found to be two—chemical and physical. The physical factor is temperature. Silica refractories from open-hearth furnace crowns show the formation of three zones; the zone nearest the interior of the furnace, which is subjected to the highest temperature, is found by petrographic analysis to consist predominantly of cristobalite; the middle zone consists mainly of tridymite, and the outer one of quartz. The chemical factor is the formation of iron silicates from the metallic charge and the silica of the refractory, and the effect of these silicates on the silica itself.

The properties and mode of formation of iron silicates are reviewed in the light of knowledge of the system $FeO–SiO_2$. It is found that the effect of the iron-silicate liquid is less destructive in an insulated than in an uninsulated furnace. It is concluded that, in addition to reducing the heat losses, insulation confers the following advantages: (1) In the insulated furnace a larger proportion of the refractory is converted to types of silica stable at high temperatures—tridymite and cristobalite; (2) in an insulated roof penetration of the molten iron silicates into the pores of the refractory does not set up such high stresses as it does in an uninsulated roof, where it sometimes leads to cracking; (3) the temperature gradient is lower in an insulated than in an uninsulated roof, and stresses due to temperature differences are less pronounced. All these factors tend to give the refractory greater stability and longer life.

"Siemensite" and its Application in the Basic Open-Hearth Furnace. E. Greiner. (Revue Universelle des Mines, 1935, vol. 11, Nov., pp. 502–506). The author reviews tests that have been made during the last few years on the use of Siemensite in the construction of open-hearth furnaces. They show the large reduction in the consumption of refractories, the increased production from the furnace, and the lengthened duration of the furnace campaign resulting from the use of this material.

FUEL

Iron and Steel Works Engineering. J. A. Thornton. (Manchester Association of Engineers, Oct. 11, 1935: Iron and Coal Trades Review, 1935, vol. 131, Oct. 18, pp. 626–627). Past progress and present achievements in iron and steel works engineering are reviewed. It is shown that important advances have been made in mechanising the coke-ovens, in increasing the size and output of the blast-furnaces and steel plant, and in rolling the large tonnages of steel now produced. In conclusion, it is pointed out that these improvements necessitate a correspondingly large production of electrical power, and, as a corollary, close attention to the boiler plant.

The Advantages of Boilers with Forced Water Circulation in Ironworks. F. Münzinger. (Stahl und Eisen, 1935, vol. 55, Nov. 21, pp. 1235–1237).

Construction and Operation of Modern La Mont Plants for Steam-Raising. H. Seidel. (Stahl und Eisen, 1935, vol. 55, Oct. 24, pp. 1134–1139). The structural details and mode of operation of the La Mont boiler are explained, and examples of its application under various conditions (including its use as a waste-heat boiler in a steelworks) are described.

The Velox Steam Generator and its Application in Metallurgical Works. W. G. Noack. (Stahl und Eisen, 1935, vol. 55, Oct. 10, pp. 1086–1091). The features of the Velox boiler are described and illustrated. It can be fired with blast-furnace and coke-oven gases, and its use in ironworks, as in hot-blast plants, &c., is referred to.

The Possibilities and Difficulties of the Measurement of Air and Gas Volumes by the Injection Method. G. Neumann. (Archiv für das Eisenhüttenwesen, 1935, vol. 9, Oct., pp. 179–183). In the injection method of measuring air and gas volumes, a measured gas stream is injected into the gas (or air) stream to be measured, the two are mixed together thoroughly, at a point beyond the mixing section of the main a sample is withdrawn, and the content of injected gas is determined; from the two measured quantities—namely, the amount of injected gas added and the amount of it present in the mixture—the volume of the gas stream to be measured is calculated. After touching on the disadvantages of the more usual methods of measuring gas volumes, the author discusses the possibilities and difficulties of the use of the injection method. He shows that it is of promise for such cases where other methods are of doubtful value, but that further rather expensive development is still necessary, even for the most simple cases. For the measurement of air and blast-furnace gas volumes, the hydrogen injection method may be regarded as technically established, but it is not a

cheap method, particularly for blast-furnace gas. It can be carried out with great accuracy; it is not, however, suitable as a means of making continuous measurements, but only for testing, checking, or calibrating measurements.

Coal Cleaning in Monmouthshire and South Wales. W. B. Davies. (South Wales Engineering Exhibition: Supplement to Colliery Guardian, 1935, vol. 151, Nov. 15, pp. 40–43). Coal obtained from the South Wales and Monmouthshire districts is cleaned either by hand-picking on cleaning belts, or mechanically by the usual wet or dry methods. Generally speaking, coal above $1\frac{1}{8}$ in. is cleaned by hand, that below $1\frac{1}{8}$ in. being sent to a washery. Large coal is commonly broken down by pin breakers to yield a sized product. Baum type washers are extensively used for small coal, and sometimes for the larger sizes also. The Rheolaveur and Chance systems are other wet systems in successful operation. Dry systems are adopted when the coal is suitable. A feature common to most of the modern plants of the South Wales area is the dedusting equipment; this in its turn has led to considerable attention being devoted to the treatment of slurry.

Coal Cleaning and Blending at Manvers Main. (Colliery Engineering, 1935, vol. 12, Nov., pp. 365–366). The coal preparation plant at the Manvers Main Colliery, which comprises a pneumatic dust-extraction plant, the washery, classifying screens, water filtration plant, and blending plant, is described.

The "Chance" Sand Flotation System of Washing Coal. A. B. Price. (South Wales and Monmouthshire Branch of the National Association of Colliery Managers: Iron and Coal Trades Review, 1935, vol. 131, Nov. 1, pp. 719–721; Nov. 8, pp. 762–763). It is shown that a coal-washing process operating on the float-and-sink principle, and employing a fluid medium intermediate in specific gravity between the coal and the dirt, offers many advantages over other methods; thus, the efficiency of the process is independent of the size or shape of the coal to be treated, it is not affected by the rate of feed or the grade of coal, and it reproduces the conditions of the normal float-and-sink test. In the Chance process the dense medium is maintained by agitating sand and water. Material below $\frac{1}{16}$ in. is removed and the plus $\frac{1}{16}$ in. coal is treated in the separating cone by means of the sand and water mixture. The overflow containing the clean coal is de-watered and de-sanded, and the clean coal is screened and passed to conveyors. Agitation is both hydraulic (by pump) and mechanical (by a revolving agitator). The refuse is drawn off from the base of the cone by a special valve system. The slurry produced by the small amount of fines remaining with the coal is caught in the sand sump, from the top of which it is drained off. The process is controlled by testing 50-lb. samples in a float-or-sink machine, using a dense liquid as the separating medium. Care is taken to prevent, as far as possible, breakage and size degradation.

The Resistance to Grinding of Coals. H. Heywood. (Colliery Guardian, 1935, vol. 151, Nov. 15, pp. 898–900; Nov. 22, pp. 941–942). Experiments were performed in order to compare the grinding characteristics of coals with their physical properties, such as strength, hardness, and toughness; the resistance to grinding was expressed as the amount of energy (in ft.lb.) required to produce 1 sq. ft. of new surface. The following methods of disintegration were used: (1) Attrition between metal surfaces; (2) crushing by a gradually applied load in a testing machine; (3) crushing by impact; (4) crushing between rollers; (5) scratch hardness test; (6) abrasion by emery cloth under standardised conditions. Tests were carried out on grades of anthracite steam coal, bituminous coal, cannel coal, and shale. The conclusions arrived at from the results of the tests are reported.

A Coke-Oven Reorganisation in West Yorkshire. (Coal Carbonisation, Supplement to Colliery Engineering, 1935, vol. 1, Oct., pp. 97–100). The original battery of 65 waste-heat coke-ovens at the Robin Hood Coke Works of Messrs. J. & J. Charlesworth has been replaced by 36 Gibbons–Kogag ovens. The throughput has not been reduced—indeed, it has been slightly improved. The ovens were built on the existing concrete mat, and the old doors were altered for use in the new installation. The oven charge is 9·1 tons and the carbonisation period 19 hr. Of the gas, 30% is surplus to requirements, and is used for power production, tar distillation, and domestic purposes. A comprehensive by-products plant deals with the tar, ammonia, &c.

New Coking Plant at Corby. (Coal Carbonisation, Supplement to Colliery Engineering, 1935, vol. 1, Nov., pp. 123–126). An illustrated description of the coke-ovens and by-products plant installed at the Corby Works of Messrs. Stewarts and Lloyds, Ltd., is given.

Increasing the Coking Power of Coal. T. Shimmura and H. Nomura. (Journal of the Fuel Society of Japan, 1933, vol. 12, p. 131: Fuel in Science and Practice, 1935, vol. 14, Oct., pp. 309–311). On the assumption that by increasing the content of γ-compounds weakly coking coals could be made strongly coking, experiments on the hydrogenation of coal under high pressure and temperature were conducted. The content of γ-compounds was in this way increased beyond 10%, with a corresponding improvement in coking quality. The increase of γ-compounds is ascribed to the conversion of α- and β-compounds by the action of hydrogen, during which much of the oxygen in the original coal is reduced, producing water. This is followed by the addition of hydrogen, if hydrogenation is prolonged, until the coal liquefies completely.

Note on the Swelling of Gas and Coking Coals. H. Cassan. (Chaleur et Industrie, 1935, vol. 16, Nov., pp. 495–508). The author describes the "C.G.C.F." (Compagnie Générale de Construction de Fours) apparatus for determining the swelling of coals and the method of carrying out tests with it; he then records some

general results and discusses them. He also gives consideration to the effect of blending on the swelling of the mixture, and to the phenomenon of the fusion of coals. He concludes with a note on the Woodall-Duckham method of estimating the swelling of coals.

Effects of Ageing on the Plasticity of Coking Coals. G. Jung. (Glückauf, 1935, vol. 71, Nov. 23, pp. 1141–1148). After describing the method of using the Gieseler "plastometer," the author gives the results of tests made on six Lower Silesian coals to determine the influence of ageing on the plasticity and coking property. The grain-size and, above all, the temperature had a great influence on the rate of ageing; this increased in proportion with the surface of the coal, and was doubled by raising the temperature by 10° C. In conclusion, the practical inferences to be drawn from the results are discussed.

The Elimination of Sulphur during the Carbonisation of Coal. T. G. Woolhouse. (Fuel, 1935, vol. 14, Sept., pp. 259–264; Oct., pp. 286–295). The author surveys the work of previous investigators in this field, and gives an account of his researches on the occurrence of sulphur in coal. He shows that during carbonisation pyritic sulphur is decomposed, giving ferrous sulphide and sulphuretted hydrogen, whilst the organic sulphur produces mainly hydrogen sulphide and volatile sulphur compounds, the remainder entering into a stable union with the carbon. The retention of sulphur by coke is due to the thermal stability of ferrous sulphide and the carbon-sulphur complex, and to their inertness towards hydrogen even at high temperatures. The author goes on to describe experiments on the quantitative determination of the decomposition of pyrites on carbonising samples of coal. The samples were carbonised at temperatures of 300° to 1000° C., and the hydrogen sulphide evolved was determined; the coke produced was subjected to the action of strong HCl and the ferrous sulphide estimated indirectly by determining the hydrogen sulphide thus evolved. From the results obtained it is concluded that pyrites in coal begins to decompose at 300–400° C., the process being complete at 550° C. Sulphuretted hydrogen is produced by the decomposition of organic sulphur, and probably by that of pyritic sulphur also. Experiments on the decomposition of pyrites by heat in an atmosphere of nitrogen pointed to a reaction represented by $2FeS_2 \rightarrow 2FeS + S_2$ up to 650° C., becoming more complex at higher temperatures. Similar experiments, using hydrogen, failed to establish any vigorous reaction with ferrous sulphide, whereas the pyrites was readily decomposed, thus: $FeS_2 + H_2 \rightarrow FeS + H_2S$, the reaction being complete at 500° C. The results of a further investigation, on the effect of carbonising mixtures of coal and pyrites, tended to confirm the stability of ferrous sulphide at carbonising temperatures, although the precise nature of the mutual reactions taking place was difficult to ascertain.

The National Coke and Oil Company Limited, Tipton Works. (Iron and Coal Trades Review, 1935, vol. 131, Nov. 1, pp. 724–727). In the Cannock process, which is in operation at the above works, the coal is pulverised and mixed with oil in the ratio of 1 : 1; the mixture is delivered to low-temperature retorts which consist of cylindrical steel vessels, externally heated and slowly revolved, where it is carbonised at 600° C. The carbonised material is screened and marketed, the material smaller than $\frac{3}{4}$ in. being briquetted. The gas drawn from the retorts is treated in a by-products plant, and is said to yield 15 gal. of petrol per ton of coal treated.

Results of Low-Temperature Coking Tests on Suitable Blends and Coal Constituents. F. L. Kühlwein. (Glückauf, 1935, vol. 71, Nov. 9, pp. 1078–1089). The author presents the results of laboratory low-temperature coking tests on Saar, Ruhr, and Upper Silesian coals, attention being paid to the mixtures and petrographical constituents of coal most suitable for low-temperature coking.

The Salermo Process for South African Oil Shales. (Fuel Economist, 1935, vol. 10, Sept., pp. 1014–1017). The material to be treated is fed to special retorts consisting of a series of semi-circular troughs along the axes of which lie steel shafts carrying T-headed paddles. The paddles revolve and promote thorough mixing of the charge; the action is one of heat and material transfer, the shale being turned over by the paddles and transferred gradually to each adjacent trough until finally the discharge end is reached. Carbonisation takes place at 450–475° C. The troughs, which are of heat-resisting steel plate, form the underside of the carbonising chamber. Gas-firing with preheated air is adopted. The process has been used on South African torbanite (an oil shale) and on Australian kerosene shale.

A New Design in Automatic Mechanical Gas Producers. A. E. Gibson. (Steel, 1935, vol. 97, Nov. 4, pp. 43–45). The construction of a new type of automatic gas producer is described. Built by the Wellman Engineering Co., Cleveland, the producer is of the revolving-body, water-cooled type. The shell is supported by an annular ring running on rollers, and rotated by a 5-h.p. motor which also drives the poker and coal feed. The blast is maintained by a dual system of steam jet and turbo-blower. A notable feature of the producer is the use of welding; thus the water-cooled shell is arc-welded from low-alloy high-tensile plate (75,000 lb. per sq. in. ultimate strength), and the stationary top and its fittings are also welded. A centralised lubricating system is adopted, and an automatic ash-removal device. The producer has a continuous gasification rate of 6000 lb. of bituminous coal per hr., and a peak capacity of 7500 lb. per hr. Nine of these producers have been designed to supply gas to the reheating furnaces of a continuous sheet mill.

Preliminary Cleaning of Blast-Furnace Gases in Cyclones. W. Barth. (Stahl und Eisen, 1935, vol. 55, Oct. 24, pp. 1129–1134).

After discussing the mechanics of the separation of dust from the gas in which it is entrained, the author compares the merits of cyclones and the usual dust-catchers used in conjunction with blast-furnaces, and shows that with the former the preliminary cleaning is much improved. By means of the principles, developed theoretically and experimentally, contained in the paper, it is possible to calculate in advance the efficiency of the dust separation in cyclones and in dust-catchers.

Fuel Economy in Iron and Steel Works. F. Bainbridge. (Cleveland Institution of Engineers, Nov. 12, 1935 : Iron and Coal Trades Review, 1935, vol. 131, Nov. 15, pp. 803–804). It is pointed out that the fuel used in the production of iron and steel is the largest single cost item, and that, in view of this, every attempt should be made to use the solid and subsequent gaseous fuels in the most efficient manner. In this connection the author examines the performance of the coke-ovens, the blast-furnace plant, and the open-hearth plant in this respect; some attention is also devoted to the operation of soaking pits and the utilisation of surplus gas for power production and general distribution.

Development and Future Possibilities of Gas as an Industrial Fuel. J. E. White. (Manchester District Association of Gas Engineers and Institute of Fuel : Gas Journal, 1935, vol. 212, Nov. 27, pp. 642–646). The author points out the directions in which extended use of gas may be made in the industrial field, and examines the circumstances in which this may be attempted. He then goes on to quote examples of the successful use of town's gas in industry, including its application to non-ferrous melting, rolling and annealing practice, and in carburising, rolling, forging, and other ferrous work.

The Utilisation of Coke-Oven Gas in Metallurgical Works. (Stahl und Eisen, 1935, vol. 55, Oct. 31, pp. 1153–1164). This is a report on the Gas Conference held in Essen on Oct. 17 and 18, 1935. Summaries are given of the following papers :—

DILLGARDT : Tasks of the Technical Bureau (*Amt für Technik*) in the Field of Technical Co-operation.

A. POTT : Previous Development of the Gas Supply in the Ruhr District.

W. EILENDER : General Problems of the Use of Coke-Oven Gas in the Iron and Steel Industry.

W. HEILIGENSTAEDT : Modern Gas-Fired Furnaces.

W. ROHLAND : Use of Coke-Oven Gas in Special Steel Works.

G. NEUMANN : Results obtained with Modern Malleablising Furnaces Fired with Long-Distance Gas.

H. KLEIN : Use of Coke-Oven Gas in the Thin Sheet Industry.

P. RHEINLÄNDER : Summarising Survey of the Industrial Use of Coke-Oven Gas.

Use of Coke-Oven and Town's Gas in Open Hearth Furnaces. J. B. R. Brooke. (Iron and Steel Industry, 1935, vol. 9, Oct., pp. 3–5). The wisdom of employing coke-oven or town's gas instead of producer gas in open-hearth furnaces depends largely on the price of town's gas, if this is used, or on the value of the disposable coke-oven gas, if it can be sold. Frequently it is economical to burn mixed gas obtained from the blast-furnaces and coke-ovens. If raw coke-oven gas or mixed gas is used, certain differences must be allowed for. Thus, coke-oven gas offers a less luminous flame than producer gas, owing to the absence of the tarry constituents. Since coke-oven gas is richer than producer gas, the regenerators should be smaller and well insulated, and care should be taken lest troubles arise through cracking of the methane in the rich gas, with the deposition of carbon in the checkers. These difficulties may be largely avoided by firing with mixed gas containing 25–30% of coke-oven gas, the remainder being blast-furnace gas. Gas of this type gives a reasonably luminous flame without choking the regenerators with carbon. In order to use mixed gases successfully, the following points should be observed: (1) The gases must be thoroughly mixed; (2) a high degree of preheat should be used; (3) the coke-oven gas content should not be less than 25%; (4) the moisture content should be as low as possible. Compared with producer gas, mixed gas may be expected to yield furnace lives as good as when using producer gas, if the foregoing points are attended to; in addition, an improved fuel consumption, owing to easier metering, may be obtained, less oxidation in the bath is likely, and the air/gas ratio is more readily controlled; there is, however, a somewhat greater tendency to foam. Mixed gas would probably be available for keeping the furnaces warm during the week-ends. The foregoing remarks apply, with modifications, to the use of town's gas instead of coke-oven gas, should the former be cheap enough.

Producer Gas for Furnace Heating. (Fuel Economist, 1935, vol. 10, Aug., pp. 982–984; Sept., pp. 1007–1009). An account of some modern methods of using producer gas efficiently for furnace heating is given. The principles of recuperative operation are set forth, together with examples illustrating the benefits to be derived from the use of preheated air and from the correct design of the burners. In the second instalment the arrangement and construction of burners for billet reheating furnaces are dealt with and the methods of recuperative and regenerative operation are briefly treated.

The Supply of Coke-Oven Gas to Derby. J. P. McCrae. (Gas Journal, 1935, vol. 212, Nov. 27, pp. 637–639). Particulars are given of the changes made in the Derby gas supply system when coke-oven gas was substituted for town's gas. Among other alterations, this entailed the laying of 15½ miles of gas main, the erection of compressing, purifying and naphthalene washing plants, and the provision of a 2-million cu. ft. gasholder.

The Development of Coal Hydrogenation by Imperial Chemical Industries, Ltd. K. Gordon. (Institute of Fuel, 1935, Nov. 22). **Billingham Hydrogenation Plant.** (Iron and Coal Trades Review, 1935, vol. 131, Oct. 18, pp. 623–624: Colliery Guardian, 1935, vol. 151, Oct. 18, pp. 715–718). In the hydrogenation process coal is made to react with hydrogen in the presence of a catalyst and at a pressure of 200 atm. and a temperature of 300–500° C. Hydrogenation takes place in either the liquid or vapour phase: coal is treated by suspending it as a fine powder in oil, into which the hydrogen is forced. The hydrogenation of coal was introduced by Bergius, and subsequently developed by the I.G. Farbenindustrie in Germany, working on brown coal, by Imperial Chemical Industries in Great Britain (using bituminous coal) and by the Standard Oil Co. in America; these concerns have pooled their technical resources. The more important improvements on the original process (and embodied in the Billingham equipment) include the use of a double-walled reaction vessel, in which the inner vessel withstands the temperature and not the pressure, while the outer vessel withstands the pressure but not the temperature (it is insulated from the inner vessel); the adoption of effective coal cleaning; and the use of chlorine and tin compounds as catalysts and the neutralisation of the resultant acid vapours with an alkaline paste. The plant is suitable for the hydrogenation of coal, creosote oil, and low-temperature tar. The yield of petrol from coal (calculated on an ash- and moisture-free basis) exceeds 60%; the yield from tars and tar oils varies from 80 to 90% by weight. It is estimated that a new plant would produce 1 ton of petrol per 3·5–4 tons of coal, calculated on an overall consumption basis. The quality of the petrol compares favourably with that obtained from the distillation of petroleum.

Testing Metallurgical Fuel Oils. J. H. Hruska. (Iron Age, 1935, vol. 136, Oct. 24, pp. 20–23, 92). The quality of fuel oil is usually estimated on the basis of specific gravity, in spite of the fact that this is not always a reliable indication of its suitability. The author is of the opinion that viscosity would be a more trustworthy criterion, and describes the Steiner viscosity test, which is shown to be quicker and more accurate than the well-known Saybolt test. In the Steiner viscosimeter the viscosity is expressed by the number of seconds required for an air bubble to rise through a very small sample of the oil to be investigated. The oil is poured into a glass tube and the top is closed, so trapping an air bubble; the tube is inverted, and the bubble gradually rises to the top again; by determining the time of travel through a stated distance the viscosity may be evaluated, and expressed in Steiner seconds or centistokes. Determinations may be carried out at a particular temperature or series of temperatures, thus enabling viscosity curves to be plotted.

PRODUCTION OF IRON

Notes on the Development of the Iron Blast-Furnace. A. J. Boynton and S. P. Kinney. (American Institute of Mining and Metallurgical Engineers, 1935, Oct., Technical Publication No. 652). The authors present notes on contemporaneous progress in blast-furnace construction and operation together with some suggestions as to the changes which seem desirable. They examine stove details, the distribution of the blast, the stack conditions, and in particular the charging arrangements. They remark that although most of the operations have been reduced to a satisfactory basis the use of the standard bell and hopper leads to uncertainty in operation and places undesirable limitations on the shape of the furnace. They suggest that a more suitable arrangement should be devised.

The Nature, Formation, and Entrainment of Blast-Furnace Dust, Studied in Terms of the Constitution of Oolitic Ores. J. P. Arend, A. Jungblut, and C. Aschman. (Revue de Métallurgie, Mémoires, 1935, vol. 32, Sept., pp. 363–392). The authors first discuss the general characteristics of blast-furnace dust, and then deal with the production of the dust in relation to the petrographic and other properties of minette ores. They next describe tests made to examine the physico-chemical reactions of minette ores which are concerned in the formation of blast-furnace dust, and the application of the results obtained to the determination of the level of the blast-furnace from which the different grains of dust originate. Under the heading of the aerodynamic relations entering into the entrainment of blast-furnace dust, they explain the theory of the carrying-over of the dust, describe an experimental verification of the aerodynamic relations, and conclude by dealing with the production of blast-furnace flue dust in relation to the development of kinetic energy in the gas in the blast-furnace and the limitation of the amount produced by means of suitable precautions which check the entrainment of the dust within the charge.

Study of the Value of an Iron Ore. R. Wintgens. (Revue Universelle des Mines, 1935, vol. 11, Oct., pp. 434–441). The iron ores entering into the composition of the charge of a blast-furnace influence the cost of production of the iron by an amount depending on their cost delivered at the works, and on the amounts of each used per ton of pig. These quantities depend on the characters not only of the ores, but also of the other materials included in the charge. In order to decide which ores are most economical to use, knowledge should be available concerning all the materials to be treated. The author presents a simple graphical method by means of which it is easy to determine the cost of the

pig iron produced by combining the ores in such a way as to produce a suitable charge from the point of view of the basicity of the slag. Thus a diagram can be drawn showing, for each tonnage of pig iron to be produced monthly, the minimum possible cost with the ores available. The attainment of the most economical charge requires important modifications in the supply of materials to the blast-furnace when the tonnage of pig to be produced varies; thus an ore which might be advantageous for a certain monthly output might no longer be so if the output were increased. The theoretical study presented in this paper is followed by an example in which this case is realised.

The Slag in the Manufacture of Ferro-Manganese. M. Déribéré. (Chimie et Industrie, 1935, vol. 34, Oct., pp. 777–779). The author first presents details regarding the operation of an electric furnace making ferro-manganese and the character of the slag employed. From the observations made it appears that there were two distinct slags, of different colours and of different compositions, which had not had time to intermix in the furnace; the author discusses their features and presents a hypothesis in regard to their formation.

Blast-Furnace Slag. J. Watson. (Iron and Steel Industry, 1935, vol. 8, Sept., pp. 457–461; vol. 9, Oct., pp. 12–13). The author shows that blast-furnace slag is a material suitable for replacing clay in the manufacture of Portland cement. By compounding the slag with the requisite amount of limestone, and burning the mixture in a rotary kiln, an excellent cement may be obtained. In France cements made by blending blast-furnace slag and calcium sulphate (as gypsum or anhydrite) are said to give satisfactory results in many cases. The sulphur generally present in blast-furnace cement does not appear to exert a deleterious effect, while the silica and lime is in a state of chemical combination which renders it resistant to the action of sea water. Further uses of slag include the manufacture of artificial stone and slag bricks, and its application as a sound insulating medium. Artificial stone may be made by pulverising slag and mixing it with powdered quicklime for pressing into blocks, which are dried and then submitted to high-pressure steam. The blocks are stated to be both hard and durable. Slag bricks are strong and water resistant, but compared with clay bricks are rather heavy. If a suitable porous slag can be produced it is likely to prove of assistance in the sound-proofing of buildings. Certain slags may already be incorporated in partition blocks, and further progress in this direction would be advantageous.

PRODUCTION OF STEEL

The Metallurgy of the Production of Wrought Steel. H. Wentrup, B. Knapp, and H. Müller. (Druckschrift der Gesellschaft von Freunden der Technischen Hochschule Berlin über das Geschäftsjahr 1934, pp. 42–53 : Stahl und Eisen, 1935, vol. 55, Oct. 24, pp. 1140–1141). Wrought steel possesses certain properties, the origin of which must be ascribed to the peculiar form of the metallurgical reactions taking place during its manufacture. It is assumed that a primary cause of the ageing of steel is the oxygen content. The puddling process is discussed; in the first stage liquid iron-silicate slag acts on a carbon-rich molten metal bath, in the second stage the same slag is in contact with solidified γ solid solution. In the piling process of making wrought steel only the second-stage reactions occur. At the puddling temperature, 1350–1400° C., the carbon should not sink below 2·5%, and this concentration keeps the oxygen content very low. If the carbon content drops below this value, iron solid solution commences to crystallise out, and its oxygen content is controlled by the interactions between it and the silicate slag; consideration of the free-oxygen content of the slag and the partition coefficient shows that the oxygen content of the metal must be well below the critical value of 0·04% given by G. Schmidt. Special tests on the reactions between oxygen-rich solid Armco iron and ferrosilicate slag showed that the latter had a strong deoxidising action on the metal, and that the oxygen in the solid iron had a notable rate of diffusion at the temperatures of wrought-steel production. The experiments provide at least qualitative confirmation of theoretical considerations on the process of wrought-steel manufacture; not only do they make the low oxygen content of the wrought-steel crystals understandable, but they also afford an explanation of the improvement of the quality of steel scrap by pile-welding.

The Corby Iron and Steel Works of Messrs. Stewarts and Lloyds, Limited. (Engineering, 1935, vol. 140, Nov. 1, pp. 471–473). **Steel Making at Corby.** (Colliery Guardian, 1935, vol. 151, Nov. 1, pp. 799–803). **The Iron and Steel Section of Messrs. Stewarts and Lloyds, Ltd., Corby Works.** (Iron and Coal Trades Review, 1935, vol. 131, Nov. 1, pp. 713–717). The new Corby Works of Messrs. Stewarts and Lloyds, Ltd., consist of iron and steel plant put down to supply their tube works on the same site, and products for the outside market. The ore treated is a low-grade carbonate containing 29–32% of iron, and rather high in phosphorus. The ore is crushed and screened, the fines being sent to a Dwight-Lloyd sintering unit, and the lump ore to the ore bins. It is smelted in three

blast-furnaces with nominal daily outputs of 300, 350, and 420 tons; the actual outputs of the furnaces so far operated have exceeded these figures. The design of the furnaces embodies the latest practice—venturi lines, automatic rotating top distributors, and so on. The ore is very dusty, and to deal with this a three-stage gas-washing plant has been installed; it consists of large individual dust-catchers at each furnace, supplemented by a group of multiple tower washers followed by an electrostatic wet precipitation plant. The cleaned gas is burnt in a battery of water-tube boilers.

Coke is produced from thirty-five vertical ovens supplemented by four Knowles type (Ω-shaped) ovens for producing coke from non-coking coal and tar. The pig iron produced by the blast-furnaces is dealt with in three basic Bessemer converters, each with a capacity of 25 tons; they are supplied with molten pig iron from a 1000-ton mixer of special design. The pig iron has the following analysis: Silicon 0·5, manganese 1·3, phosphorus 1·9, sulphur 0·05% (carbon not stated). The metal from the converters is run into 25-ton ladles to be teemed into ingots. The latter are cogged down in a 40-in. reversing blooming mill; and the billets so produced are reheated and sent to the strip mill, comprising eight horizontal and four vertical stands. The first two are 22-in. three-high roughing stands; they are followed by a vertical mill and two stands of 19-in. rolls, and by a group of four continuous three-high finishing stands in conjunction with interchangeable vertical edging stands. Finally, the strip is led to coilers and so to the cooling conveyors to be subsequently transhipped.

Improving Open-Hearth Furnace Design. W. C. Buell, jun. (Steel, 1935, vol. 97, Sept. 9, pp. 53–55; Sept. 16, pp. 44–47; Sept. 23, pp. 81–86; Sept. 30, pp. 38–42). Continuing this series, the author deals with the distribution and flow of gases in regenerator chambers. He examines the effect of fantail design and checkerwork arrangement on the flow conditions in the regenerators. The design of the checkerwork, and the calculations involved, are considered, with illustrative examples.

Improving Open-Hearth Furnace Design. W. C. Buell, jun. (Steel, 1935, vol. 97, Oct. 7, pp. 53–61; Oct. 14, pp. 55–57; Oct. 21, pp. 54–58). The author continues his discussion of regenerators, and analyses the thermal and related data from five open-hearth furnaces; he remarks on the paucity of suitable concise and accurate information bearing on the heat balance in open-hearth furnaces. A number of automatic records of regenerator temperatures are presented and discussed. The temperature conditions at the regenerators are considered, together with figures relative to the combustion of the gas supplied to the furnace; the method of estimating the heat balance is also indicated.

Improving Open-Hearth Furnace Design. W. C. Buell, jun. (Steel, 1935, vol. 97, Oct. 28, pp. 46–50; Nov. 4, pp. 58–62; Nov. 11, pp. 56–64; Nov. 18, pp. 60–64). The author concludes his dis-

cussion of regenerator practice by considering the heat exchange effects. He shows that the heat exchange depends on three coefficients: The coefficient of transfer from furnace gas to the brickwork; the coefficient of transfer from the brickwork to the air or producer-gas; and the overall coefficient of heat transfer (combining the foregoing). He explains how the results are obtained and set out, with reference to examples of proposed regenerator systems.

The author then proceeds to deal with the design of flues. He first describes the conventional layout, originally adopted by Siemens, and goes on to examine some of the more modern flue systems using slide valves. This is followed by details of the size of and the gas flow in the various parts of the flue system. Charts and data relating to the flow conditions in typical flue systems are reproduced. The final article considered in this group treats of the construction and design of the valves used for reversing the flow of gas to and from the furnaces. Butterfly, water-sealed, and slide valves are considered in turn, with comments on the relative effectiveness of each type; the superior efficiency of the water-cooled slide valve is remarked on. (*See* Journ. I. and S.I., 1935, No. II., p. 376.)

Temperature Measurement of Liquid and Solid Metals Exemplified by Reference to Iron. R. Hase. (Zeitschrift des Vereines deutscher Ingenieure, 1935, vol. 79, Nov. 9, pp. 1351–1355). The precision methods for measuring temperatures which have been developed for scientific investigations are generally too complicated and expensive for use in the works. In the present paper, the author deals primarily with such appliances and processes which are suitable for the works measurement of the temperatures of liquid and solid metals. By paying particular attention to the physical principles involved, he indicates the limits of applicability of the various instruments.

The Steelmaking Processes in the Light of the Economy of Materials and Energy. H. Bansen. (Stahl und Eisen, 1935, vol. 55, Nov. 14, pp. 1205–1214). Only about half the iron required for the manufacture of steel is available in the form of scrap; the remainder is provided by the reduction of ore. The production of iron from ore is a thermal problem, and the development of iron and steel production is based on advances in thermotechnology. The mechanical and thermal methods of ore preparation lead to losses of iron, and only relieve the blast-furnace so far as the function of slagging is concerned. The Krupp direct process carries the thermal preparation up to the stage of producing lumps of metallic iron in the gangue and separating them from it. From the viewpoint of heat economy and costs, the blast-furnace is the most satisfactory means of carrying out reduction and smelting. The hearth furnace is only suitable for refining, and will be superseded by the large electric furnace. The oxidising zone occurs in all metallurgical processes; it is useful; but the process worked must be adapted to suit this condition. Diagrammatic representation

for all the methods of steelmaking, from the all-scrap charge to the all-pig charge, reveals the material, thermal and output conditions of each case.

Further Notes on Open-Hearth Boils. H. B. Hibbard. (Iron Age, 1935, vol. 136, Sept. 26, pp. 98, 104, 108). Notes on the boiling phenomenon in open-hearth practice—including its effect on killed and on rimming steel—are furnished.

Recent Progress in Steel Making Reported from Germany.—IV. S. Epstein. (Metals and Alloys, 1935, vol. 6, Aug., pp. 219–222). Two defects in steel—sand seams and flake—are discussed. In Germany attempts were made to correlate the occurrence of sand seams with furnace practice, and it was found that late heats and dirty steel tended to promote the formation of sand seams. The cause of flakes is less certain but may be connected with the absorption of hydrogen in steels during melting.

Recent Progress in Steel Making Reported from Germany.—V. S. Epstein. (Metals and Alloys, 1935, vol. 6, Sept., pp. 247–251). The developments reported in this article deal with slag control in open-hearth furnaces, the use of manganese in the open-hearth charge, slag tests (by judging the appearance of samples cast into flat discs), jolting ingots during solidification, and the direct rolling of molten steel. (*See* Journ. I. and S.I., 1935, No. II., p. 383.)

Quality Control of Basic Electric Steel. R. P. Brown. (Metal Progress, 1935, vol. 28, Oct., pp. 89–93, 96). Some notes on the practice of the Timken Steel and Tube Co., in the production of basic electric steel, are presented. The furnaces comprise one 10-ton furnace, two 30-ton furnaces, and one capable of dealing with 100 tons of steel; they are all of the Heroult type; the bottoms are of periclase, fired *in situ*, the lower side walls are of magnesite, and the upper side walls and roof are of silica. The steel scrap, limestone, and other materials employed are of high purity. During melting the composition and temperature of the bath are kept under constant control. A reducing slag and a reducing atmosphere are maintained in the furnace. The author explains the ways in which electric melting practice differs from ordinary basic open-hearth practice; the chief differences appear to be the closer control over the furnace conditions made possible by electric heating, and the higher temperatures obtainable.

High-Frequency Induction Furnace Steel Plant. (Engineering, 1935, vol. 140, Nov. 8, pp. 513–514). **High-Frequency Induction Furnaces.** (Engineer, 1935, vol. 160, Nov. 22, p. 551). The two high-frequency electric induction-furnace steel melting plants installed at the works of Messrs. Samuel Osborn and Co., Ltd., Sheffield, are described. They comprise a 350-kW. unit serving two ½-ton furnaces, and a 150-kW. installation serving two ¼-ton furnaces. All the furnaces are arranged to tilt. The larger furnaces are provided with automatic control and hydraulic tilting gear, and the smaller furnaces are equipped with manual control and

electric tilting gear. Only one of the furnaces in each unit can be used at a time, the change-over being performed by switch gear. This enables greater flexibility to be attained, however, since one furnace may be shut down for repairs while the other is being operated; or one lining may be acid and the other basic. The generating unit for the 350-kW. installation consists of a high-speed motor-generator set, the motor being of the squirrel-cage type and the generator of the inductor homopolar type. The motor is supplied at 440 V. from a three-phase transformer with an input of 11,000 V. The power factor of the high-frequency supply is maintained at or near unity by an automatic relay and meter system which controls the number of condensers in circuit across the furnace coil. The generating unit for the 150-kW. installation is constructed on similar lines to the larger unit, but manual control is used. The furnaces are used for the production of high-quality rustless and heat-resisting steels and high-quality alloy steels.

Copper Stools for Ingot Moulds.—II. C. E. Williams and H. B. Kinnear. (Metals and Alloys, 1935, vol. 6, Aug., pp. 213–217). Copper stools are stated to have lives six or eight times those of iron stools, while they increase the life of the moulds by from 30 to 100% and reduce stripping costs. Temperature measurements made by introducing thermocouples into the stool and mould revealed that the temperature throughout the copper stool was much more uniform than that of the cast-iron stool, whilst the actual temperature reached was lower. This is made clear by isotherms. (*See* Journ. I. and S.I., 1935, No. II., p. 391.)

The Heterogeneity of Steel Ingots. W. H. Hatfield. (Newport Metallurgical Society, Joint Meeting with Iron and Steel Institute, Oct. 12, 1935: Iron and Steel Industry, 1935, vol. 9, Nov., pp. 57–65). The author commences by referring to the work of the Ingot Committee, the results it has achieved, and the results it has still to achieve, and then proceeds to examine certain aspects of that work. He remarks that even with the knowledge now obtained it is scarcely possible to predict the degree of heterogeneity to be expected in any particular type of ingot, since the variables are many, and are often incompletely known; furthermore, ease of fabrication must often take precedence over purely metallurgical considerations like that of homogeneity. Thus, ideally it would no doubt be preferable to produce completely sound ingots free from pipe or blowholes, but for practical and commercial reasons this is not possible. The author goes on to discuss the segregation characteristics of certain types of ingot. He shows that the segregation may be revealed by zoning, and that the extent to which segregation takes place is greatly affected by the rate and temperature of teeming. In commenting on the type of segregation associated with rimmed ingots, he suggests that although the reaction between the carbon and oxygen in the steel (giving rise to carbon monoxide) may be to some extent responsible

for rimming, it seems probable that the allotropic changes in the δ-γ region are an equally valid explanation. Experiments with centrifugal casting have disclosed other effects which are sufficiently interesting to warrant further investigation. In conclusion, the author refers to certain branches of the work of the Ingot Committee—those dealing with the oxygen and nitrogen contents of steel, ingot moulds, and pyrometry—which have also received, and will continue to receive, close attention.

Gaseous and Solid Impurities in Ingots. J. H. Andrew. (Midland Metallurgical Societies, Oct. 3, 1935: Iron and Coal Trades Review, 1935, vol. 131, Oct. 4, pp. 559–560). The commonly accepted explanation of segregation in steel ingots—namely, differential solidification—does not, in the author's opinion, suffice to explain the high segregation which is so often observed. He submits a theory which attributes segregation to the chemical action between the carbide present and the ferrous oxide, with the formation of carbon monoxide and the expulsion of the interstitial liquid owing to the pressure of that gas. In support of this theory the case of rimming steel is cited. The author goes on to discuss inverse segregation and the use of molybdenum as a deoxidiser. In conclusion, he touches on the problem of gases in steel, quoting, in this connection, certain results contained in the Sixth Report on the Heterogeneity of Steel Ingots published by the Iron and Steel Institute.

Finishing the Heat of Steel. J. H. Hruska. (Blast-Furnace and Steel Plant, 1935, vol. 23, May, pp. 322–324; July, pp. 469–470; Aug., pp. 536–537; Sept., pp. 619–620, 643). The first article deals with piping in ingots; theoretical pipe curves are presented and compared with those obtained in practice. In the second article ingot dimensions are given attention, the ingot thickness and height, and the relation between these quantities being considered. The third instalment treats of the subject of taper in ingots. It is shown that the amount of taper depends on the type and size of the ingot and on the fancy of the manufacturer. The salient features, advantages and drawbacks of square, slab, and polygonal ingots are examined, together with the leading dimensions commonly adopted, in the fourth article. (*See* Journ. I. and S.I., 1935, No. I., p. 384.)

The Impurities and the Purification of Steel. A. Portevin. (Bulletin de la Société des Ingenieurs Soudeurs, 1935, vol. 6, Aug.–Oct., pp. 1914–1930: Génie Civil, 1935, vol. 107, Nov. 30, pp. 517–520). The author first points out that the noxious effect of an element generally does not apply to all the properties of the steel, so that an element which may be an "impurity" under one set of conditions may actually be desirable under others; further, the effect produced depends on the amount of the element in question and on the condition in which it is present. The author next discusses inclusions and dendritic segregation, and finally reviews

methods of removing impurities, concluding with a short note on the Ugine–Perrin process of treating steel by violent agitation with a suitable slag.

Non-Metallic Impurities in Open-Hearth Steel. F. W. Sundblad. (Iron Age, 1935, vol. 136, Nov. 14, pp. 21, 76, 77). The author suggests that the occurrence of non-metallic impurities in open-hearth steel is closely related to the boils associated with the chemical reactions which take place. Three types of boil may be distinguished: Lime and iron ore boils, which are oxidising, and a third type, the bottom boil. In all three cases the character of the slag is a major factor; a thin slag aids deoxidation, but may also lead to foaming (in high-carbon heats, for instance) and the introduction of slag inclusions into the bath; this is particularly so with the bottom boil, but applies also to lime and iron ore boils. These considerations are especially important in the large-scale production of high-quality steel.

REHEATING FURNACES

Notes on Heating Furnace Economy and Operations. W. H. Mawhinney. (Metal Progress, 1935, vol. 28, Oct., pp. 33–34, 38). The author presents a number of practical hints on the economical operation of forging, heat-treating, carburising, and similar furnaces. Among the matters touched on, the following are included: The rate of heat input to the furnace; the fuel consumption, in terms of B.Th.U. per lb. of material heated; the overall cost of operation; and the method of operating the furnace.

Furnaces for the Heavy Forging Industry. H. Southern. (Metal Treatment, 1935, vol. 1, Autumn No., pp. 123–126, 131). Particulars of the heavy forging furnaces installed at the Vickers Works of the English Steel Corporation are furnished. The furnaces, seven in number, are designed for reheating both straight carbon and alloy steel ingots. Three are equipped with bogies, and four are of the fixed hearth type; they differ in size in order to ensure the economical reheating of the widest possible range of ingots. The furnaces are fired with producer gas from an adjacent producer, and they are equipped with air and gas regenerators. The largest is capable of taking ingots up to 250 tons in weight; it is of the bogie type, 26 ft. 10 in. long, 17 ft. wide and 13 ft. high; the bogie itself is 30 ft. long and 11 ft. 7 in. wide, and has been designed to support a total load of 450 tons. These furnaces serve a 7000-ton forging press.

High-Temperature Conveyors. A Novel Type for Heating Furnaces. W. E. Blythe. (Iron and Steel Engineer, 1935, vol. 12, Oct., pp. 16–22). Although the use of roller-bottom continuous heat-treatment furnaces offers certain advantages over other types, the high cost of the alloy-steel rollers required has hitherto constituted a serious disadvantage. The author gives details of the design and performance of a new type of disc roller of light construction, supported by small rollers inside the furnace. The bearings appear to withstand the furnace conditions without wearing excessively, and the extra mechanical power required is not a serious item. The improved tightness of the furnace leads to a lower fuel consumption, and the cost of the alloy steel required is said not to be excessive. Some furnaces fitted with these rollers are described and illustrated.

Experiments on the Losses by Burning in Rolling-Mill Furnaces. First Part. Temporary Influences. F. Strähuber. (Stahl und Eisen, 1935, vol. 55, Nov. 21, pp. 1229–1234). The author describes tests made with a roller-type reheating furnace to determine the factors governing the metal losses (by burning). The furnace was

worked in the normal way, but the end and side burners were adjusted to give (*a*) a reducing atmosphere at the discharge end and an oxidising atmosphere at the charging end, (*b*) a reducing atmosphere, (*c*) an oxidising atmosphere, or (*d*) perfect combustion, throughout the entire furnace. In addition to determining the influence of the furnace atmosphere, answers were sought to the following questions : (i) Is the loss for rough ingots the same as that for ingots with metallically-clean (turned) surfaces ? (ii) How great is the loss in relation to the total heating time ? (iii) What influence has the length of the partial heating time in the middle and discharge sections of the furnace, *i.e.*, in the most critical temperature range above 900° C., on the losses in pusher furnaces ? (iv) What is the effect of prolonged sojourn in the discharge section of the furnace ? (v) What is the effect of breakdown in the rolling process, *i.e.*, stoppages, which, because the furnace is kept hot, usually lead to an increase in the temperature, particularly of the back parts of the furnace ?

The author gives the details of his tests, and then summarises the results diagrammatically. He shows that the extent of the losses is determined by the following four (frequently overlapping) factors : (*a*) The length of stay in the middle and discharge sections, *i.e.*, at temperatures above 900° C. ; (*b*) the soaking period in the discharge section ; (*c*) the furnace atmosphere ; and (*d*) the discharge temperature. The factors (*a*) and (*b*) are discussed briefly ; (*c*) and (*d*) are to be dealt with in a later part of this work.

FORGING, STAMPING AND DRAWING

Vibration-Proof Hammer Foundations. W. Zeller. (Stahl und Eisen, 1935, vol. 55, Oct. 24, pp. 1141–1142). The author first discusses the mechanics of the action of a hammer plant and of the vibrations set up, and shows what conditions must be fulfilled for the transmission of the vibrations from the foundations to surrounding objects to be prevented; he concludes by giving a practical example of the calculation of the design of a vibration-proof foundation for a hammer.

Advances in Sheet Metal Working Practice. (Metal Industry, 1935, vol. 47, Oct. 25, pp. 417–418). For forming operations, rubber cushions are often used in the bolster of dies for sheet metal work. These have the disadvantage of exerting a progressively increasing pressure towards the end of the working stroke. Pneumatic die cushions do not suffer from this drawback; moreover, they have the additional merit of flexibility, enabling the pressure to be applied or removed, as required. Several such cushions are illustrated and described.

Crankless Power Presses for Making Large Auto Body Stampings. R. W. Glasner. (Iron Age, 1935, vol. 136, Nov. 14, pp. 24–29, 74). The trend of automobile body design towards the use of large pressed units has necessitated attention to the raw material (steel sheets of large dimensions and uniform thickness), the dies (which are bigger) and the presses. Heavier presses have not entirely met the situation, since certain difficulties arise—notably a tendency for large die slides to go out of parallel—with the conventional type of construction. The author describes a press designed to overcome these troubles. The press is crankless; each corner of the slide has an individual drive taken from a central motor and flywheel. The bull gears are located directly above the four corners of the slide. Integral with the bull gear is the eccentric; the pin carrying this assembly is mounted on the press frame, the load being taken in shear. The vertical movement of the slide is obtained by an eccentric strap. All four jibs are adjustable, enabling the slide to be properly aligned. The slide is counterbalanced by compressed air cylinders. The use of the crankless press is stated to lead to greater certainty of operation and less wear on the dies.

Significance of Tests on Automobile Body Sheet. J. C. Arrowsmith. (Metal Treatment, 1935, vol. 1, Autumn No., pp. 117–120). Automobile body sheet is usually obtained from basic open-hearth rimming steel; ingots of this steel consist of a rim of pure material surrounding a centre of segregated impure steel—a degree of heterogeneity which persists in the rolled sheet, leading to a

considerable variation in the quality of different portions of the same sheet. In addition to this, there is commonly a lack of uniformity between sheets from the tops and bottoms of the ingots and also between sheets from the first and last ingots cast. These factors must be allowed for in testing sheet for cold pressing; several sheets should be selected from each consignment and a number of determinations made on each sheet. The cupping test is useful but not very discriminating, and it does not completely simulate cold-pressing conditions. The tensile test enables a good idea of the cold-working properties of the material to be gained. In particular, the elongation should be adequate, and a high ultimate strength associated with a moderate yield point (to permit local stretching) are desirable. However, the simple tensile test scarcely reproduces the complex conditions which obtain during deep drawing, and to remedy this the wedge-draw test has been introduced. In this test a specimen with tapered and parallel sections is pulled through a tapered die, and the elongations on each portion are measured.

The Deep-Drawing of Sheet Steel. L. B. Hunt. (Iron and Steel Industry, 1935, vol. 9, Nov., pp. 54–56). The author points out that although simple pressing of dead-mild sheet steel offers few difficulties, the operation of deep-drawing requires considerable care and experience. The problem of stretcher strains, temper rolling and its effect on hardness, and the responsibility for scrap are among those which call for investigation. The author suggests that it is the practical considerations, such as the technique of press operation, which require attention rather than the purely academic questions.

The Elimination of Physical Defects in Deep-Drawing Steels. T. G. Grey-Davies. (Sheet Metal Industries, 1935, vol. 9, Aug., pp. 487–488; Sept., pp. 548–550). Physical defects in deep-drawing steels may be due to a variety of causes, and with some of these the author deals. He points out that the presence of unwanted elements may have a deleterious influence on the quality of the steel; thus, tin, if present to an extent greater than 0·10%, gives rise to cracking in the subsequent drawing operations. Inclusions—which may be derived from a number of sources—are equally undesirable. The quality of the steel is also affected by the rate of teeming and the design of the ingot moulds. Upon reheating practice depends to a large extent the occurrence (or absence) of laminations in sheet material.

Testing of Deep-Drawing Materials. H. Kayseler. (Zeitschrift des Vereines deutscher Ingenieure, 1935, vol. 79, Nov. 2, p. 1346). As a means of testing the deep-drawing properties of sheet materials, the author suggests that the specimens should be prepared in a wedge-shape; on drawing the wedge through a flat draw-plate, the material is submitted to varying degrees of deformation. Erichsen cupping tests are then made at various

positions on the deformed specimen, and in this way information is obtained regarding the effect of different degrees of previous deformation on the results obtained in the cupping test.

The Exclusion of the Influence of the Sheet Thickness in the Deep-Drawing Test by the Erichsen Method. A. von Vegesack. (Zeitschrift für Metallkunde, 1935, vol. 27, Oct., pp. 227–235). The author first sets out to analyse the stresses developed in the specimen in the Erichsen test, and shows the difference between the stresses in the cupping and in the tensile test. In order to exclude the influence of the sheet thickness on the test results, recourse can be had, as in the determination of the elongation of a tensile specimen, to the concept of standardisation for the gauge length, but for the Erichsen test interchangeable standard testing machines, suited to the particular thickness under test, become necessary. When various sheet thicknesses are tested in the same standard machine, the "normality" (a factor expressing the degree of departure from the standard conditions) is raised for thin and decreased for thick sheets; the function normality/thickness can be expressed by a simple formula. Given the working hypothesis that the functions indentation/normality and normality/thickness are identical, a formula for the function indentation/thickness is developed. The usefulness of this formula was tested by reference to the known D.I.N. curves, and a curve for the same purpose calculated from an empirical formula proposed by K. Daeves; the agreement, though not perfect, was fairly good, and certainly adequate for practical purposes.

Comparison of the calculated and actual test results obtained with annealed, low-carbon, cold-rolled strip steel also revealed satisfactory agreement; the deviations observed were due to the difficulty of producing sheets identical in every respect but of widely differing thicknesses. The author suggests that it is wrong to use a single standard machine for widely differing thicknesses, and proposes that a pair of machines should be employed; each machine would be designed for a certain range of thickness, and within these ranges the standard indentation would be calculated by means of the formulæ put forward. The standard indentations so determined on the several standard machines would stand in the same relation to one another as the dimensions of the machines. The deep-drawing ability of a material can then be conveniently expressed on a uniform scale. To simplify the calculations by means of the formulæ proposed, it would be an advantage to supply each standard machine with ready-prepared tables of conversion.

Electrically-Heated Wire Patenting Furnace. O. Junker. (Stahl und Eisen, 1935, vol. 55, Oct. 31, p. 1167). A very brief description and illustrations are given of the Junker electrically-heated wire patenting furnace. The output is about 275 kg. per hr.; when empty, about 15 kW. are required to maintain a temperature of 900°; the current consumption is about 230 kWh. per ton.

The Manufacture of Spring Wire. R. Saxton. (Wire Industry, 1935, vol. 2, Oct., pp. 331–333). Although attempts have been made to quench spring wire immediately the coil has left the rolling train, these have not been entirely successful, and the normal method of reheating and subsequently quenching is adopted. The wire is usually heated in a continuous annealing furnace maintained at a temperature of 900° C. Water may be used as the quenching medium, but spent hydrochloric acid from the cleaning department, or a weak solution of common salt, furnishes superior results. It is possible to use a high-carbon steel and obtain the required elastic properties by drawing alone, but a more reliable product is obtained from a low-carbon steel (0·20–0·30% of carbon, 0·3–0·5% of manganese) in the quenched and drawn conditions. The author describes the drawing procedures adopted for close and open (upholstery) springs.

Coppering Fine Sizes of Mild Steel Wire. A. W. Fielding. (Wire Industry, 1935, vol. 2, Oct., pp. 327–329, 333). To obtain a firmly adherent coat of copper on mild steel the wire must be perfectly clean, a condition best attained by pickling in cold 5–10% sulphuric acid, using flour as an inhibitor. For coppering, a dilute solution of copper sulphate and sulphuric acid must be used, again using flour in the solution. The wire must remain in the solution until the coating is sufficiently heavy, and must then be promptly placed in the drawing tub, with the minimum exposure to air possible. The dies should be perfectly polished and correctly formed if the copper coating is to be retained during the drawing operations. The drawing solution should be alkaline, to obviate any risk of acid rust. If a bright finish is required, not more than one or two holes should be drawn after lacquering.

Notes on the Use of Back Pull in Wire Drawing. P. M. Mueller. (Wire and Wire Products, 1935, vol. 10, Sept., pp. 419–426). After analysing the effect of back pull on wire-drawing, the author comes to the following conclusions: Back pull is an important factor in wire-drawing, and must be taken into consideration when computing the power required for cascade drawing; its effect is to reduce the bearing pressure on the die, and hence the friction losses. By making use of the back pull, the power required for drawing operations may be lessened; it is probable that die and maintenance costs will in this way be reduced.

Grain Size and its Influence on the Manufacture of Steel Wire. B. L. McCarthy. (Wire Association, Oct. 2, 1935: Iron Age, 1935, vol. 136, Oct. 10, pp. 14–19; Oct. 17, pp. 23–27, 80–82: Wire and Wire Products, 1935, vol. 10, Sept., pp. 359–373). Chief attention is paid to the use of the McQuaid–Ehn test as a guide in the melting of basic open-hearth steel and in the selection of steel for cold-drawing; the test may be also made to indicate the normality of the steel, and hence the amount of dissolved oxides contained therein. It is explained that the necessary control of

grain size in fine-grained steel may be accomplished by the use of aluminium as a deoxidiser. The ultimate grain-size of patented wire depends very largely on the temperature at which the austenitic grains coarsen. In this connection it seems to be desirable to employ a coarse-grained steel for the manufacture of patented wire, since this gives rise to a coarse structure in the finished article; but it is also important that the constituents be completely dissolved in patenting, or poor results will be obtained.

Special Steels in Wire Form. R. Saxton. (Wire and Wire Products, 1935, vol. 10, Oct., pp. 469–472, 488, 489, 490). The author considers the various types of alloy steel suitable for cold-working and discusses their salient properties, the heat treatment required, the preparation for wire-drawing, their behaviour on being drawn, and other characteristics of interest to the wire-drawer.

Cold Heading Wire. L. D. Seymour. (Wire and Wire Products, 1935, vol. 10, Sept., pp. 414–418). The author discusses in this article principally the application of the cold-heading process to wire, the mechanics of cold-heading, and the effect of heat treatment on medium-carbon wires suitable for this process. The characteristics of rimmed and killed steels are compared with respect to the requirements of material for cold-heading work. In addition, the proper treatment of steel for medium-carbon cap screws is indicated.

ROLLING-MILL PRACTICE

Investigations on the Power Consumption in Rolling Ingots. H. Hoff and T. Dahl. (Stahl und Eisen, 1935, vol. 55, Nov. 7, pp. 1182–1186). Earlier experiments of the authors have been repeated and extended with improved measuring apparatus; the previous results on the power consumption in rolling ingots were confirmed. The electrical heat losses in the driving motor, the no-load work of the mill, the work of acceleration, the additional work under load, and the power transmitted by the shafts were determined. The composition of the material rolled had an influence on the power requirement; the influence of certain alloying elements was very considerable. Of particular importance was the roll design, which led to the conclusion that in reversing blooming mills the number of passes should be a minimum, that is, the draught should be as great as possible. The power transmitted by the shafts varied according to the diameter of the rolls; this variation should be as small as possible in order that the stressing and power transmission should be uniform. The greater the work of pure deformation, the greater is the efficiency of a rolling-mill.

Instantaneous Power and Speed of Rotation of the Driving Motor of a Reversible Train of Rolling-Mills. M. Steffes. (Chaleur et Industrie, 1935, vol. 16, Sept., pp. 425–426). The author presents a graph showing the power absorbed by, and the speed of rotation of the motor driving a reversible two-high rolling-mill with rolls 900 mm. in diam., while rolling ordinary joists weighing 55 to 167·2 kg. per m. run. The rolling was effected in thirteen passes, and the maximum power absorbed and the corresponding speed of rotation at every moment during each pass are indicated.

Roll Designing for Section Steel. C. Holzweiler and T. Dahl. (Stahl und Eisen, 1935, vol. 55, Oct. 10, pp. 1081–1086; 1936, vol. 56, Jan. 16, pp. 57–68). The authors describe their method of roll draughting for the production of various standard **H** and **I** sections. The first article deals with the simplest case in order that the rules for designing rolls for these sections may be clearly set out; in this scheme the passes in the middle roll are not used more than once and false passes are provided. This method requires rolls of great length or the use of more than one stand, particularly for heavy sections. In the second article the authors show how the heavier sections can be rolled with the same number of passes and shorter rolls by the inclusion of a roughing mill, or in one mill by designing the passes so that the grooves in the middle roll can be used twice.

Composition Roll-Neck Bearings. H. M. Richardson. (Steel, 1935, vol. 97, Sept. 16, pp. 22–24). The Textolite bearings made by the General Electric Co., which are described, are manufactured from the following basic materials: Cotton fabric, synthetic resin of the phenol-formaldehyde type, and finely-divided graphite of low ash content. The fabric is impregnated with the phenolic resin and graphite, cut into pieces and laid in the mould so as to form laminations. The material is moulded at a pressure of 2000–4000 lb. per sq. in. and a temperature of 160° C. The resin fuses and hardens, and the moulded bearing is removed and machined. Since it is highly elastic—the elastic modulus of compression is 500,000 lb. per sq. in.—high bearing pressures may be carried without distress. Water lubrication is adopted, the friction at rubbing speeds between 400 ft. per min. and 2100 ft. per min. being considerably less than with the conventional grease-lubricated metal bearing. Composition bearings may be successfully applied to blooming, rail, sheet, rod, and plate mills, and to cold-rolling mills, if the operating speeds are in excess of 100 ft. per min.

Moulded Plastic Mill Bearings Effect Large Power Savings. H. F. Horne. (Steel, 1935, vol. 97, Nov. 11, pp. 36–37). An outline of the production and application of Micarta moulded plastic bearings is presented. The bearings are manufactured by moulding, under heat and high pressure, layers of fabric impregnated with phenolic resin. It is stated that these bearings enable a power saving of 20–40% to be made, reduce the necessity for operation of the screwdowns, eliminate the cost of oil and grease lubrication and display a greater durability than the conventional metal type. They are also superior to lignum-vitæ bearings. Details of the application of these bearings to merchant mills, strip mills, skelp mills, bar and billet mills and blooming and hot sheet mills, are furnished.

Roller-Bearing Applications in Continuous Strip Mills and Rod Mills. S. M. Weckstein. (Iron and Steel Engineer, 1935, vol. 12, Oct., pp. 23–30). The author has selected a recently designed continuous strip mill as an example of the application of roller bearings to this type of mill, and to rod mills; units for both hot and cold mills receive consideration. Among the roller-bearing applications to which attention is drawn are the following: Roll necks, a combination gear drive and pinion stand, a vertical edging mill, pinch rolls for a flying shears, and a drum drive for a cold strip reel. Typical methods of mounting, adjusting, and aligning these bearings are also described.

Lubrication of Anti-Friction Bearings. J. I. Clower. (Iron Age, 1935, vol. 136, Oct. 3, pp. 14–17, 86, 88). In this article an account is given of the functions of lubricants for anti-friction bearings, the properties which these lubricants should exhibit, and the factors affecting the choice of lubricants.

Irlam Rod Mill. (Iron and Steel Industry, 1935, vol. 9, Oct., pp. 14–15). A description of the continuous rod mill in operation

at the Irlam Works of the Lancashire Steel Corporation, Ltd., is presented. Three bars may be rolled simultaneously, and there is provision for a fourth. The billets, $2\frac{1}{8}$ in. square by 30 ft. long, are heated in a recuperative producer-gas-fired furnace. They are delivered to the mill by a billet pusher. The roughing mill consists of seven continuous stands driven by a 1600-h.p. motor; the four following stands are arranged in pairs, each pair being coupled to a 750-h.p. motor. These are succeeded by two looping stands, both powered by 500-h.p. motors. There are two finishing mills, each of six stands and driven by a 1200-h.p. motor; the rods on leaving the roughing section are diverted to either of the finishing mills. There is provision for automatic reeling (reeling being continuous) and conveyor cooling incorporating a water-cooled muffle.

New Strip Mill at the Meadow Hall Works of Arthur Lee & Sons, Ltd. (Iron and Coal Trades Review, 1935, vol. 131, Oct. 25, pp. 672–676). The new mill is designed to produce hot-rolled strip from 1 in. to 16 in. wide and down to the thinnest gauges. The billets are heated in a producer-gas-fired furnace which embodies a special soaking zone. The hot billets are sent to the cogging mill; this consists of two three-high stands, with 21-in.-dia. rolls, and driven by a 1500-h.p. induction motor through helical gearing. The cogged billet is delivered to either of two units, according to the width of strip being rolled. Strip 5 to 16 in. wide is rolled in No. 1 unit, comprising three stands, each with three rolls, the top one being a backing-up roll for the smaller middle roll. No. 2 unit consists of a train of five stands of three-high rolls provided with repeaters, interchangeable roll frames, and a quick roll-changing device; strip below 5 in. wide is dealt with in this mill. A third unit follows No. 2 unit, consisting of two stands similar to those in No. 1 unit; by its use the strip can be reduced to 21 gauge. In addition to the rolling-mill, comprehensive auxiliary equipment is installed.

The Influence of the Rolling Conditions during the Cold-Rolling of Strip Steel. W. Lueg. (Stahl und Eisen, 1935, vol. 55, Oct. 17, pp. 1105–1112). In the rolling of strip steel at room temperature, the rate of rolling, and the material of the rolls, as between chromium-steel and chilled-iron rolls, have practically no effect on the rolling process. On the other hand, the roll diameter, the composition, condition, and section of the material being rolled, the friction, and the draught have a very great influence. For economy in rolling and the avoidance of excessive spread, in existing plants the lubrication must be ample, the surface condition of the rolls and rolled material good, and the roll-faces as hard as possible, in order that the coefficient of friction in the roll-opening may be satisfactory. In new plants the diameter of the working rolls should be made as small as possible, so long as the desired draughts can be obtained without slipping of the material. The use of smaller roll diameters,

besides causing lower frictional losses and greater elongation, has the advantage that the rolls suffer less deflection, owing to the smaller resistance to deformation, the result of which is a greater uniformity of final thickness across the width of the rolled strip.

Manufacture of Locomotive Tubes. (Iron and Steel Industry, 1935, vol. 9, Oct., pp. 8–11). Tubes for locomotive boilers are produced from open-hearth steel containing between 0·18 and 0·20% of carbon and less than 0·35% each of sulphur and phosphorus. The ingots are forged, and cut into rounds which are inspected and tested for subsequent conversion into seamless tubes. They are pierced by the Mannesman, Stiefel, or Erhardt process, reduced by the Diescher or Wellman Peters process, and finally cold-drawn, inspected, and tested.

Ingot-Slicing and Trepanning and Drilling Machines. (Engineering, 1935, vol. 140, Oct. 18, pp. 416–417). The ingot-slicing lathe consists of a bed of the box-section type provided with two headstocks, one of which is loose, the other being driven by a 100-h.p. A.C. motor through a four-speed gear-box. Four saddles are fitted on the front ways of the bed and four on the rear, each saddle being fitted with a slide to carry two tools. The slides are provided with mechanical and manual traversing gear; the loose headstock may also be traversed along the lathe bed by a 2-h.p. motor. The maximum length of ingot which can be admitted is 8 ft. 3 in., and the maximum diameter is 24 in.

The trepanning machine is designed for boring the sprag-holes in steel disc wheels. Two, three, or four holes are machined in one operation. The machine is fitted with four 3½-in.-dia. spindles having eight speeds; the wheels are carried on a rotating chuck with two vertical faces, so that one wheel may be removed and replaced while the other is being bored. Wheels ranging from 2 ft. to 4 ft. 6 in. in dia. may be machined.

Peels 8¼-in. Round Billets at Rate of 20 Tons an Hour. M. M. McCall. (Iron Age, 1935, vol. 136, Sept. 19, pp. 25–27). Billets 8¼ in. in dia. are turned to 8 in. dia. at the rate of 20 tons an hour on the machine described in this article. Billets up to 12 in. in dia. and 12 ft. long may be accommodated in the machine. Cutting is carried out by a revolving circular cutting-head through which the billet is fed by a carriage actuated by hydraulic pressure. A carriage on the discharge side grips the turned billet and pulls it through. Two operators are sufficient to work the machine.

WELDING AND CUTTING

A New General-Purpose Meter for Resistance Welding. C. Stansbury. (Journal of the American Welding Society, 1935, vol. 14, Sept., pp. 32–35). The new meter is based on the fact that a Neon tube (*i.e.*, lamp) requires a definite critical voltage for the establishment of a glow discharge, although such a discharge, even for as short a period as one cycle, can readily be seen. By tapping a suitable rheostat shunted across the appropriate transformer winding, this critical voltage may be found and the transformer voltage (or current, as the case may be) easily calculated. In this way the primary and secondary current, the welding voltage, and the duration of the weld may be measured. The duration is obtained by the use of a timing condenser. A current transformer for measuring the actual welding current presents difficulties, owing to the high current involved. An air-core transformer was devised consisting of a wooden toroid on which fine coils of wire were wound; it was found to give quite satisfactory results. The author suggests that although the accuracy of the glow-tube meter is less than that of a D.C. ammeter, it may be considered to approach $\pm$ 5% and is therefore adequate for many purposes.

Resistance Welding Extensively Employed in Automotive Industry. J. A. Weiger. (Iron Age, 1935, vol. 136, Nov. 7, pp. 20–24). The resistance welding processes used in the motor-car industry may be classified as (1) spot welding, (2) flash butt welding, (3) electrical upsetting, (4) seam welding, (5) projection welding. Machines in the first class include the conventional spot welders; machines in which the parts are assembled and welded one spot at a time, by bar, portable, and gun welders; those in which the parts are assembled and the spot welds are made at the same time, by multiple electrodes; hydromatic welders, in which perhaps several hundred welds are made in one cycle, but not all necessarily at the same time. Flash welding is largely employed for welding up the body panels and chassis units. Petrol tanks are commonly seam welded; for small parts, projection welding is used. In all types of resistance welding the material used for the electrode tip or die is important, and water-cooling is essential.

Resistance Process Applied to Welding Copper-Plated Steel Tubes. (Iron Age, 1935, vol. 136, Oct. 24, p. 35). Two appliances are described. In the first the petrol and air tubes for a motor-car fuel system are welded together side by side for a certain distance. The welding is done by pulling the tubes through freely-running weld rolls, the process being that of resistance welding. The second application of the resistance process concerns a method of forming a double-

walled tube from copper-plated steel strip. The strip is formed and then passed to the welding rolls. These consist of two pairs of grooved rolls at a certain distance apart, one roll in each pair being insulated and the other two attached to the secondary terminals of the welding transformer; in this way the length of tube forms a resistance element. On emerging from the rolls the welded tube is passed through a deoxidising chamber, fed by a small gas flame, in order to maintain a bright finish. The equipment produces $\frac{5}{8}$-in. tube at the rate of 30 ft. per min.

Preventing Distortion in Longitudinal Seams in Welded Pressure Vessels. J. T. Phillips. (Journal of the American Welding Society, 1935, vol. 14, Sept., pp. 26–27). A method of avoiding distortion in welding the longitudinal seams of cylindrical vessels is described, in which backing bars and binding bars are attached to the inside of the seam and hydraulic jacks applied in order to produce a slight out-of-roundness (a small outward bulge). Welding is proceeded with, and on completion, it is found that the distortion due to welding has neutralised the initial bulge at the seam, and thus the drum maintains its circularity. Vessels up to 25 ft. long, 2 ft. in dia., and built of plates more than 2 in. thick have been fabricated in this way.

Some Effects of Generator Characteristics on Welding Costs. J. H. Blankenbuehler. (Journal of the American Welding Society, 1935, vol. 14, Sept., pp. 36–38). After discussing the volt-ampere characteristics of welding generators, the author gives test data concerning the performance of welding generators on an efficiency basis.

COATING OF METALS

Calorising Process is Improved. J. B. Nealey. (Iron Age, 1935, vol. 136, Oct. 24, pp. 28–29). The improved calorising process is stated to produce a hard aluminium-alloy surface on the steel which is both tough and adherent. Pipes are calorised by sealing them into a retort together with the calorising mixture and charging the retort into a gas-fired furnace, where it is revolved while being heated to 1500–1800° F. The pipes are removed, cleaned in boiling water, resealed in a second retort, and again reheated, and finally straightened, sized, and ground on the ends. Pots and similar items are treated in large boxes. Miscellaneous parts are pickled in an immersion gas-heated tank prior to calorising; dip calorising (similar to dip galvanising) is used for parts which require a bright coat of pure aluminium.

Defects in Galvanising on Steel Sheets due to Imperfect Basis Material. M. von Schwarz and H. Fromm. (Korrosion und Metallschutz, 1935, vol. 11, Nov., pp. 241–245). Tests were made to show the influence of the microstructure of the steel sheet on the quality of the galvanised coating. In an earlier publication the authors had asserted that for perfect galvanising the carbon content of the sheet should not be less than 0·05%, and should exist as much as possible as lamellar pearlite, and not as grain-boundary cementite or nodular pearlite. In the present work they found that the more completely the carbon in low-carbon sheets was converted to cementite in strings or at the grain boundaries, the better was the coating; conversely, the greater the amount of pearlite in or near the cementite strings or grain-boundary cementite, the worse was the coating (it is assumed that threads of piping, unwelded skin blow-holes, large hollows, slag nests, marked segregation, &c., are absent from the surface). In explanation of their observations, the authors suggest that the process of "unmixing" or breakdown of the lamellar pearlite after critical cold-working in the last passes of the hot rolls and in flattening, followed by critical box-annealing, sets up differences in the specific volume of the carbon-carrying component. Pure pearlite and pure free cementite at the grain boundaries represent equilibrium conditions where the carbon-bearing component is tightly embedded in the ferrite, whereas the intermediate stages of "unmixing" set up micro-capillary hollows or internal stresses. The hollows become occupied by hydrogen during pickling, and at the temperature of galvanising this gas is ejected, and disturbs or prevents the crystallisation of the zinc; likewise, the stressed iron can take more hydrogen into solid solution

during pickling. Thus, lamellar pearlite without free cementite is the safest form for the carbon to assume; grain-boundary cementite without any lamellar pearlite appears to be equally good, but it is doubtful if the production of this structure by box-annealing is as certain as that of lamellar pearlite by normalisation.

Development of the Continuous Vitreous Enamelling Furnace. W. Marshall. (Institute of Vitreous Enamellers: Foundry Trade Journal, 1935, vol. 53, Nov. 7, pp. 349–350). The growing displacement of cast-iron enamelled ware by sheet-iron parts has led to the introduction and subsequent development of continuous furnaces for firing these parts. Early furnaces for vitreous enamelling were of the muffle type; semi-muffle furnaces were afterwards adopted, in which only the muffle hearth separated the combustion chamber from the furnace proper. In its turn the semi-muffle was replaced by the directly (but intermittently) fired furnace operating on alternate firing and heating cycles. It was realised that muffle furnaces still retained certain advantages, and when ultimately continuous furnaces were adopted, the box-type full-muffle principle was incorporated; the furnaces were of the conveyor, U-type, cross-fired by multiple burners. Certain difficulties were at first experienced—the occurrence of longitudinal draughts, for instance (overcome by using an air seal)—but these have been surmounted, and the continuous U-type furnace may now be considered to be the standard furnace for enamelling domestic sheet-iron ware.

Opacifiers Used in the Vitreous Enamel Industry. W. Astles. (Institute of Vitreous Enamellers: Foundry Trade Journal, 1935, vol. 53, Nov. 7, pp. 351–353). Certain heavy metallic oxides confer upon enamel the property of opacity. The commonest opacifiers are tin oxide, zirconium oxide and silicate, and antimony oxide. Less dense oxides and metallic compounds are also used, but they usually have low refractive indices, and are therefore less effective. Tin oxide appears to be the most widely used opacifier; its density is 6·95 and its refractive index is 2·04. Zirconium oxide, with a density of 5·75 and a refractive index of 2·23, is also highly successful. Other oxides, which are added as additional opacifiers, include zinc oxide, calcium oxide, barium oxide, boric oxide, alumina and silica. Antimony oxide is extensively used in frits for bath enamels and other purposes.

Notes on Furnaces for the Vitreous Enamelling Industry. T. Teisen. (Institute of Vitreous Enamellers: Foundry Trade Journal, 1935, vol. 53, Dec. 5, pp. 417–418). Among the aspects touched on by the author are the application of recuperative firing to vitreous enamelling furnaces, the relative advantages of gas- and oil-fired furnaces, refractories and insulation, the types of muffle employed, and the use of dryers.

CORROSION OF IRON AND STEEL

Congress on Corrosion, 1935. (Stahl und Eisen, 1935, vol. 55, Dec. 5, pp. 1459–1463). **German Symposium on Corrosion.** (Iron and Coal Trades Review, 1935, vol. 131, Dec. 13, p. 989). Very brief summaries are given of the papers presented at the Fifth Congress on Corrosion organised by the Verein deutscher Chemiker in co-operation with the Deutsche Gesellschaft für Metallkunde, the Deutscher Verein von Gas- und Wasserfachmännern, the Verein deutscher Eisenhüttenleute, and the Verein deutscher Ingenieure, and held in Berlin on Nov. 18–19, 1935. The broad theme of the Congress was " Corrosion by Cold Water."

Errors in Corrosion Research. R. B. Mears and H. E. Daniels. (Electrochemical Society, 1935, Preprint No. 68–16). By means of simple statistical methods the probable errors for all the Cambridge corrosion experiments conducted under controlled-temperature conditions have been calculated. The error may be divided into two components: (1) the error of measurement, and (2) the error due to variations in the material under test. In the case of the experiments under consideration, it was found that for corrosion losses greater than 3 mg. the error in the result is due almost entirely to variations in the material; for losses less than 3 mg. the error due to experimental causes becomes of increasing importance, and in this category an improvement in technique can be expected to increase materially the accuracy of the determinations. A statistical analysis of Borgmann and Evans' measurements of the corrosion rates of rolled zinc sheet half-immersed in potassium chloride solutions of various concentrations indicates that the curve connecting corrosion velocity and concentration actually does continue to rise, under special conditions, up to the highest salt concentration employed.

The Corrosion-Resistance of Metallic Materials, particularly Rustless V2A Steel, in Cooling Brine (including Galvanic Effects). P. Schafmeister and W. Tofaute. (Technische Mitteilungen Krupp, 1935, vol. 3, Nov., pp. 223–226). In ice-making plants attempts have always been made to minimise or prevent the corrosion caused by the brine solution—on the one hand, by the addition of various substances to the brine itself, on the other, by the choice of various metals for the parts undergoing attack. The latter method sets up the problem of electrolytic action; the authors consequently made laboratory tests on this point, and found that when dipped in brine and in electrical content with other metals *V2A* steel always behaved

cathodically, *i.e.*, was unattacked. In practical tests the same observation was made, but for various reasons the intensity of the currents flowing were much less. The implications of these currents in regard to the amount of corrosion and possible danger to the plant are discussed.

Corrosion-Fatigue in Colliery Ropes. S. M. Dixon and M. A. Hogan. (Engineer, 1935, vol. 140, Oct. 25, pp. 436–437). In view of the marked difference in the behaviour of cold-drawn steel wire and other materials when subjected to repeated stressing, no safe analogy between them can be drawn. Hence the authors have undertaken fatigue experiments on wire for colliery ropes. Tests were carried out in air and under the corrosive action of a water-spray, using an electro-magnetic fatigue testing machine. The fatigue limit for plough steel wire (125 tons per sq. in. tensile strength) was 31·8 tons per sq. in. in air, and about 11 tons per sq. in. for wire exposed to corrosion-fatigue. Examination of the fractured corrosion-fatigue specimens revealed the presence of surface cracks. Discussing these results, and some rope failures which have come to their notice, the authors consider that corrosion-fatigue may often be the cause of failure in colliery ropes. The access of shaft water, atmospheric moisture, and dust are factors likely to promote corrosion. In view of the fluctuating nature of the load applied to colliery ropes, and of the severe service conditions, it is particularly desirable that adequate protection should be afforded; of the methods adopted, galvanising appears to be one of the most effective.

The Corrosion of Lead Alloy Coated Steel Cylinders Used as Fire Extinguishers. W. L. Hewitt. (Journal of the Society of Chemical Industry, 1935, vol. 54, Dec. 20, pp. 1094–1095). Pinhole punctures in the alloy coating of steel cylinders used as fire extinguishers were not found to be responsible for corrosive attack when specimens were immersed in sodium bicarbonate solution (the reagent contained in extinguishers). On the other hand, with larger exposed surfaces, electrolytic action takes place, but the existence of a potential difference between the exposed and unexposed areas, is not sufficient to explain the corrosive attack which is known to occur, especially since the protected metal in the lead/iron cell is the iron. Steel immersed in bicarbonate solution is normally protected by the formation of a film of oxy-carbonate. It is the breakdown of this film which initiates corrosion.

REFRACTORY MATERIALS

(Continued from pp. 3A–6A)

Developments and Trends in Refractories. L. J. Trostel. (Blast Furnace and Steel Plant, 1935, vol. 23, Sept., pp. 621–622, 624, 625, 632; Oct., pp. 703–705, 720; Nov., pp. 775–776). **Recent Developments and Trends in Refractories.** L. J. Trostel. (Iron Age, 1935, vol. 136, Nov. 21, pp. 18–21, 90, 92, 94; Dec. 2, pp. 26–29, 95). The author comments on some of the more important advances in the manufacture of refractories which have taken place in recent years. It is shown that by attention to sizing and grinding, by the use of increased moulding pressures and firing temperatures, and by de-aerating the mixture and pre-stabilising the grog, improved refractories have been produced. Attention is then directed to certain new refractories such as mullite (from cyanite), sillimanite, andalusite and others of the aluminium-silicate type. The Ritex process is shortly described, and some space is devoted to insulating firebrick and refractory concrete. The applications of these materials are briefly referred to.

Modern Practice in Heat Insulation. C. Ellis. (Engineering and Boiler House Review, 1935, vol. 49, Sept., pp. 170–176; Nov., p. 354). The application of heat insulation to the field of steam engineering is considered. After discussing the general problem of heat insulation, the author deals with the classes of material available, and their suitability for various types of service. Slag wool, glass wool, asbestos, aluminium foil, cork, and magnesium products are considered in turn; finally, the heat loss from underground piping is briefly touched on.

Metallic Heat Insulation. J. T. Nichols. (Mechanical Engineering, 1935, vol. 57, Oct., pp. 621–624). It is possible to secure a high degree of heat insulation by employing as the insulating media metal sheets arranged with air spaces in between. The sheets reflect the radiant heat which comprises a large proportion of heat transfer at relatively low temperatures. Moreover, it is found that black plate, in the hot-rolled and annealed or full-finished state, reflects low-temperature radiation almost as well as a bright metallic surface such as tinplate or cold-rolled strip. The efficiency of this type of insulation may be estimated in two ways. In the first method a box containing ice, and insulated with the material under test, is placed in a hot room at a steady external temperature; the inner and outer surface temperatures of the box, and the rate of melting of the ice, are measured, and from these data the coefficient of heat transfer is computed. This method is suitable for testing refrigerator insulation. In the second method (for testing pipe-coverings) an electrically heated pipe is used, the input to which is measured, as well as the surface temperatures of the pipe and insulation.

FUEL

(Continued from pp. 7A–14A)

The Fusion Point of Coke Ash. G. E. Foxwell. (Coal Carbonisation, Supplement to Colliery Engineering, 1935, vol. 1, Nov., pp. 114–116). After briefly describing the mineralogical characteristics of coke ash, the author examines the problem of ash fusibility, with particular reference to some results obtained by Tweedy.

The Ignition Temperatures of Solid Fuels. J. Roberts. (Coal Carbonisation, Supplement to Colliery Engineering, 1935, vol. 1, Dec., pp. 135–138, 142). The author examines the methods hitherto adopted, and describes a new form of apparatus for determining ignition temperatures, employing a salamander crucible, a pyrex glass tube, and a thermometer. The crushed fuel is placed at the bottom of the crucible and the glass tube upon it; when the crucible is heated from below, a current of air is induced to pass through the layer of coal, the temperature at which the fuel begins to glow being taken as the ignition temperature. Some typical results on coal, coke, and low-temperature coke are recorded.

Some New Data on the Fundamentals of Gas Combustion. E. O. Mattocks. (Metal Progress, 1935, vol. 28, Oct., pp. 21–26). The author distinguishes and describes three types of gas flame: that in which none of the air required for combustion is mixed prior to burning; that in which part of the air is supplied and mixed with the gas; that in which the whole of the air necessary for combustion is mixed with the gas. In the latter case the high temperature produced may give rise to dissociation of the gaseous products of combustion, and the formation of hydrogen and carbon monoxide which does not entirely re-associate. Dissociation may be repressed by introducing excess air. The author suggests that the actual space required for combustion is comparatively small, and that in view of this a furnace should consist of a combustion chamber (and, if necessary, a heat exchanger) and an adjacent work chamber. To obtain the best heat distribution the maximum rather than the minimum number of burners should be employed. If slow combustion rates, and long luminous flames are required, nozzle-mixing burners, in which mixing and combustion take place after the gases have left the nozzles, may be usefully adopted.

Measurement of Gas Flow to Furnaces. J. R. Ratcliff. (Wild-Barfield Heat-Treatment Journal, 1935, vol. 1, Dec., pp. 84–89). The author first briefly indicates the reasons why a fuel meter is a necessary part of furnace equipment, and subsequently deals with each class of meter in turn. These are divided into: (*a*) the positive displacement, or bellows type, (*b*) rotary, fan or inferential meters, (*c*) float or gate indicating meters, and (*d*) differential meters, in

which the stream of gas is made to flow through an orifice or venturi tube. A brief indication of the relative advantages and sphere of application of each type is given.

Determination of the Angular Relation in Radiation Exchange by Means of Photography. E. Eckert. (Zeitschrift des Vereines deutscher Ingenieure, 1935, vol. 79, Dec. 14, pp. 1495–1496). A simple optical method for the estimation of the transfer of heat by radiation from one surface to another is described and its application is explained by means of examples.

Note on the Use of Metals in the Construction of Recuperators. Choisy. (Chaleur et Industrie, 1935, vol. 16, Aug., pp. 379–381). The author first discusses various thermal factors influencing the temperature of the metal in metallic heat exchangers, touches on the use of such recuperators operating in tandem behind two refractory-built regenerators, and then gives consideration to the protection of the cast iron or steel used in the metallic recuperators against corrosion by the gases in contact with them.

British Coals, their Analyses and Uses. (Fuel Economist, 1935, vol. 11, Nov., pp. 82–84). A further collection of analyses and characteristic thermal data of British coals. (*See* Journ. I. and S. I., 1935, No. II., p. 338).

The Cleaning of Coal. Vieux. (Revue de l'Industrie Minérale, Mémoires, 1935, No. 359, Dec. 1, pp. 581–589). A review of the washing of coal, the treatment of fines and slimes, and dry cleaning.

Coal-Cleaning and Grading Plant at the Rising Sun Pit. (Iron and Coal Trades Review, 1935, vol. 131, Nov. 29, pp. 895–899). **Coal-Preparation Plant at the Rising Sun Colliery, Wallsend.** (Engineering, 1935, vol. 140, Dec. 6, pp. 605–608). A description of the coal-cleaning and grading plant at the Rising Sun Pit of the Wallsend and Hepburn Coal Co., Ltd., is presented. (*See* Journ. I. and S. I., 1935, No. II., p. 341).

The Drying of Washed Coal. (Memorandum No. 18, Utilisation of Coal Committee of the Institution of Mining Engineers, 1935). Beyond a certain small quantity—say 6%—the moisture in coal is an undesirable and often deleterious ingredient; it reduces the efficiency of carbonisation in coke-oven and gas-works practice and the calorific value of steam coal. The moisture may be reduced by drainage at bunkers or in wagons, by de-watering screens and by centrifuges; but these methods have definite disadvantages (such as the time required, and the slurry formed) which are not, however, associated with thermal drying. In thermal dryers hot gases are allowed to come into contact with the wet coal, and almost any desired reduction in the moisture content is possible. The thermal efficiency of thermal drying is of the order of 60%. The cost of removing 6% of moisture from coal in a dryer treating 40 tons of coal per hour need not exceed 3d. per ton of coal, and may be less.

The Clarification of Washery Water and the Recovery of Coal Slurry. J. L. Lewis. (Colliery Guardian, 1935, vol. 151, Nov. 15,

pp. 895–897). Particulars are given of the "Unifloc" reagent for the treatment of coal slurry. (*See* Journ. I. and S. I., 1935, No. II., p. 341).

"Sensitisation" and other Observations on Slurry Flocculation. E. T. Wilkins. (Journal of the Society of Chemical Industry, 1935, vol. 54, Nov. 29, pp. 391T–393T). Certain hydrophilic colloids, such as starch and gelatin, are among the best flocculators for washery slurries, and results have been obtained with these reagents which do not appear to be in accordance with the charge neutralisation theory of flocculation. Electrolytes appeared incapable of flocculating graded particles over 240 mesh (0·066 mm.) in size, but starch was capable of flocculating suspensions of closely graded coal particles up to 0·3 mm. in dia. Negatively-charged slurries appeared to be flocculated equally by negatively- or positively-charged gelatin, and the removal of electrolytes from the system did not affect the flocculation properties. The flocculation of the coarse particles of slurries by hydrophilic colloids is attributed to a modification of the surface properties of the coal, &c., by the absorbed layer of colloid, so that the collisions normally occurring during sedimentation result in adhesion. The effect of "wetting agents" (such as turkey red or acetic acid) and other surface-active substances has been investigated. Although these substances by themselves had little or no effect on the settlement rate of a slurry, certain "difficult" slurries could be sensitised in this way so that they became much more amenable to flocculation by starch or gelatin; these sensitisers did not increase the flocculating power of electrolytes.

Investigations on the Filterability of Coal Slimes and Flotation Concentrates. A. Götte. (Glückauf, 1935, vol. 71, Nov. 9, pp. 1097–1100). After touching on previous methods of examining the filterability of fine-grained coal material, the author describes a new testing apparatus and the method of using it.

Dewatering of Coal Slimes and its Cost when Using Vacuum Filtering Plant. H. Paul. (Glückauf, 1935, vol. 71, Dec. 7, pp. 1193–1199). The author first discusses the troubles that arise in coal-cleaning plants from the occurrence of coal slimes, and then describes measures by means of which they may be overcome. Particular attention is drawn to vacuum cell filters; data from practical operation are quoted, showing that outputs of 750–1000 kg. per sq. m. and final moisture contents of 18–25% can be attained. Finally the cost of the method is dealt with; figures taken from practice show the cost of filtering to amount to 0·17–0·24 *RM.* per sq. m. per hr., or 0·23–0·32 *RM.* per ton of moist coal below 1500 μ grain-size.

Development in the Coke-Oven Industry. (Coal Carbonisation, Supplement to Colliery Engineering, 1935, vol. 1, Dec., pp. 147–149). It is pointed out that there is evidence to show that the coke-oven industry is stagnating; in particular, the main market for the coke—the blast-furnace—is no longer expanding. The market for domestic

coal is also declining, since this fuel is being replaced by coke, gas, and electricity; it is suggested that attention should be directed towards the domestic fuel market, and that a national organisation, similar to the successful London and Counties Coke Association, be set up to regulate the selling side of the industry.

The Coke-Oven Industry in the U.S.S.R. I. J. Solovyov. (Coal Carbonisation, Supplement to Colliery Engineering, 1935, vol. 1, Dec., pp. 139–142). Before the war the coke industry in Russia was largely confined to the Don basin, and most of the plants were small installations at the pit-head, with no provision for the recovery of by-products. During recent years, however, a number of new coke-producing districts have been developed. The estimated output for 1935 is 17·5 million tons—four times the 1913 production. The present tendency is to include coke works in industrial groups (or " combinates ") producing iron and other metals, so that the gas may be utilised. The usual types of oven—Becker, Otto, Koppers, &c.—are employed, and work is going on with the object of developing a new oven free from the defects of those now in operation. Work is also being done on the quality of the coal, with special reference to the ash, sulphur, and phosphorus contents.

A Dry Coke-Cooling Plant. (Coal Carbonisation, Supplement to Colliery Engineering, 1935, vol. 1, Dec., pp. 143–146). Particulars are given of the Collin coke-cooling installation in operation at the plant of the South African Iron and Steel Industrial Corporation, Ltd. The coke is cooled in an inert gas, a mixture of atmospheric nitrogen and carbon dioxide.

Temperature Readings in Coke Ovens. L. G. Jones. (Blast Furnace and Steel Plant, 1935, vol. 33, Nov., pp. 759–762). After emphasising the necessity for the close temperature control of coke-ovens the author discusses the method of measuring the temperatures and of making use of the results obtained.

Carbonisation of Coal. W. B. Warren. (Industrial and Engineering Chemistry, 1935, vol. 27, Nov., pp. 1350–1354). The results are reported of a series of experiments on the carbonisation of a typical coking coal in which the rate of heating was changed at various temperatures during each run. The object of the work was to determine whether the effects noted in previous studies—*i.e.*, an increase in the yield of tar and decrease in the yield of coke as the rate of heating over the whole range was increased—could be related directly to the rate of heating through any particular temperature interval. Two rates of heating—1·4 and 21·8° C. per min.—and three series of tests up to a maximum temperature of 700° C., were used in several combinations. From the results it is concluded that the thermal history up to and beyond the plastic range is important, since no direct correlation could be made between the effects observed and the rate of heating through the plastic range alone. The data show that the rate of heating through the preplastic range is of prime importance in determining the yields

of carbonisation products and gas composition. Coke hardness, on the other hand, is determined largely by the rate of heating through the plastic range. In general, it is concluded that theories to explain the carbonisation process cannot be built up on the basis of the plastic range alone.

Determination of the Total Volume of Vapour and Gases Evolved by Thermal Decomposition of the Various Kinds of Coal and their Petrographic Modifications. W. Swietoslawski and H. Brzustowska. (Fuel in Science and Practice, 1935, vol. 14, Oct., pp. 307–308). The authors present the results of determinations of the volume of gas evolved during the carbonisation of certain varieties of coal and their petrographic constituents. The experiments were carried out at temperatures varying from 370° to 530° C., on samples of anthracite, bituminous coal, vitrain, durain, &c. They discuss the behaviour of the coals and represent the results obtained in graphic and tabular form.

Electrical Conductivity of Coke. J. D. Davis and H. S. Auvil. (Industrial and Engineering Chemistry, 1935, vol. 27, Oct., pp. 1196–1200). The authors have studied the electrical conductivities of ten types of coke obtained from American coals carbonised at temperatures ranging between 500° C. and 1100° C. Apparatus was used in which the ground sample was contained in a cylindrical mould and subjected to high pressure (60,000 lb. per sq. in.); the conductivity was estimated by a Wheatstone bridge. The results show that the conductivity of cokes made from the same coal depends upon, and increases with, the carbonising temperature. The average conductivity of cokes produced at 1100° C. is 260,000 times that of cokes produced at 600° C. The quantity and quality of the volatile matter contained in the coke affect its conductivity to a marked extent. The logarithm of the resistance is a straight-line function of the volatile matter, the slope of the line depending on the carbonising temperature of the coals. Other factors being equal, the conductivity of low-volatile or volatile-free cokes varies with the length of the plastic range as shown by the Layng–Hathorne test. Coke conductivity diminishes with a decrease in the coal rank; the relation is only general, however, and may not hold for individual cokes.

Foundry Coke. W. E. Mordecai. (Institute of British Foundrymen, and Coke-Oven Managers' Association, Nov. 23, 1935 : Colliery Guardian, 1935, vol. 151, Dec. 13, pp. 1079–1080 : Foundry Trade Journal, 1935, vol. 53, Dec. 12, pp. 437–438). In this paper the author discusses the carbon content of coke and its effect on carbon "pick-up"; the sulphur "pick-up"; the ash content; the size and density of the coke, and its reactivity.

PRODUCTION OF IRON

(Continued from pp. 15 A–16 A)

The Dillingen Ironworks. H. van Ham. (Stahl und Eisen, 1935, vol. 55, Dec. 19, pp. 1536–1541). The author describes the foundation and development of the Dillinger Hütte, a firm which has recently celebrated its two-hundred-and-fiftieth birthday. The works are in the Saar District.

The Dimensions and Profile of a Modern Blast-Furnace. M. A. Pavloff. (Seventh International Congress on Mining, Metallurgy, and Applied Geology, Paris, Oct. 20–26, 1935 : Revue de Métallurgie, Mémoires, 1935, vol. 32, Oct., pp. 451–465). The author discusses and compares developments in recent years in the dimensions and profiles of blast-furnaces in the United States of America, Germany, and Russia, and their influence on the working and outputs of the furnaces.

Complete Solution of the Problem of the Hot-Blast Stove. M. Derclaye. (Seventh International Congress on Mining, Metallurgy, and Applied Geology, Paris, Oct. 20–26, 1935 : Revue de Métallurgie, Mémoires, 1935, vol. 32, Oct., pp. 427–450). The author first presents a mathematical discussion of the thermal exchanges taking place within a hot-blast stove and the factors controlling them, and then applies these considerations to the study of three types of hot-blast stove. In his conclusions the author asserts that the two-zone stove has no special advantage over the single-zone stove; he adds that the efficiency of a hot-blast stove could be raised by preheating the combustion air to 60–70° C. by passing it through a space formed by the dome and a false cupola, thus recovering a large proportion of heat now lost there by radiation.

Gas Flow in the Blast-Furnace and the Influence on it of the Mode of Charging. W. Feldmann and J. Stoecker. (Stahl und Eisen, 1935, vol. 55, Dec. 26, pp. 1559–1564). The authors record the results of experiments which show the influence of the manner of charging a blast-furnace on the distribution of the gas across the upper furnace section. In the tests the coke and ore were charged either together in the usual way, separately, or sometimes specially mixed; further, the weights of the charges were varied from the normal to one-and-a-half times to twice as much. As a measure of the gas flow, the CO_2 contents of the gas at various positions across the furnace section were determined; where the charge was most porous the gas flowed most rapidly and the CO_2 content was least. Curves show the influence of the mode of charging on the gas distribution, that is, primarily on the variation of density of the burden in the furnace; the authors discuss them and their indications regarding the distribution of the charge materials as they fell

from the bell and rolled on the uneven surface of the stock. Which mode of charging is most advantageous depends on local conditions, particularly on the furnace profile and on the type of tuyeres in use. Of greater importance to the economical working of the furnace than the uniform distribution of the gas is undisturbed operation; this, in most cases, is attained by the arrangement of a narrow zone near the furnace wall through which the gas can pass freely, the gas distribution across the rest of the cross-section being uniform.

A Contribution on the Preparation of Blast-Furnace Flue Dust. H. Wortner. (Stahl und Eisen, 1935, vol. 55, Dec. 12, pp. 1513–1514). Given a constant gas velocity across the entire cross-section of a dust-catcher, it is theoretically possible to separate out definite particle sizes of dust from the gas. The author's experiments are intended to form the basis for the practical application of this theory. The dust from the blast-furnaces of two works was examined; in each case samples were drawn from the gas stream close to the furnace and near to the gas-cleaning plant. Sieve analyses of the dusts are recorded graphically and discussed; the smaller proportion of coarse particles in the samples taken from the end of the gas main is noted. The finest dust particles tended to " ball-up," and this is attributed to the condensation of gaseous constituents as the temperature fell. The change of colour from light grey for the coarse to black for the fine dust pointed to differences of composition between the particle sizes, but attempts to determine the differences microscopically were unsuccessful. The iron contents of the dust samples drawn close to the blast-furnace were 26·4 and 37·1%, and those taken just before the cleaning plant were 5·13 and 15·7%, respectively; this reduction of the iron content by about 80 and 60% is important for the problem under consideration.

As means of separation, the sink-and-float method, using acetylene tetrabromide, was used for the iron-rich coarse dust after preliminary centrifuging, while for the fine dust sedimentation analysis was employed. The results of the sink-and-float tests are tabulated; the light particles were found to be practically free from iron, while the iron content of the heavy particles approached that of the ore smelted.

The third task concerned the enrichment of these iron-rich particle sizes. By means of the specific gravities of the sieve fractions (determined in a vacuum pyknometer) and the density and viscosity of the blast-furnace gas (which acts as the carrier) the rates of fall of the fractions were calculated; that of the heaviest was found to be 6·65 m. per sec. and of the lightest 0·42 m. per sec. The author concludes that the enrichment of the valuable iron-bearing fraction of the dust in the dust-catcher should be possible in practice, and he touches on the dimensions of the dust-catcher and the gas velocity required for its attainment.

Metallurgical Problems and Possibility of Adjustment to the Raw Material Situation. H. Bansen. (Stahl und Eisen, 1936, vol. 56,

Jan. 2, pp. 1–10). The author is concerned with the situation of the German iron and steel industry from the point of view of the availability of raw materials. Diagrams showing the "circulation" of iron, manganese, and phosphorus demonstrate the dependence of Germany on imports; they also show how, if necessary, the requirements could be covered from native sources. Here the problems of winning and treating the ores enter into the question. There are several ways of separating iron from the gangue, but their utilisation is bound up with well-defined metallurgical and economic considerations. The most important points are the conservation of manganese and desulphurisation. To attain these objects, the many pig-iron kinds, usual up till now, must be reduced to a few which would be suitable for all purposes but would result in a better "yield" of manganese. Steel can be produced in ways ranging from all-scrap to all-pig processes. It is shown that the basic Bessemer process will remain the basis of steel production, though certainly the composition of the pig charged will require alteration. The open-hearth will be superseded by the large electric furnace. The merits of the processes and methods to be used must not be judged solely from the economic point of view; the metallurgical aspect must be the determining factor.

The Situation of the Iron and Steel Industry in Czechoslovakia. O. Quadrat. (Seventh International Congress on Mining, Metallurgy and Applied Geology, Paris, Oct. 20–26, 1935: Revue de Métallurgie, Mémoires, 1935, vol. 32, Oct., pp. 469–481). The author reviews briefly the evolution of the Czechoslovak iron and steel industry, gives notes on the raw materials, plants, products, &c., of the blast-furnaces, steel works, rolling-mills, forges, foundries, &c., in the country, and concludes with some statistical data on the industry.

History of Iron Manufacture. M. Paschke. (Giesserei, 1935, vol. 22, Nov. 8, pp. 553–561). The author touches on iron production in early times; the bloomery process (*Rennfeuerverfahren*); the refining process (*Frischfeuerverfahren*); the charcoal blast-furnace; the coke blast-furnace; crucible steel; blister steel; malleable cast iron; the puddling process; the invention of the steam engine, railways; the introduction of hot blast for melting; the first London World Exhibition; the Steel Age; modern research problems, &c.

FOUNDRY PRACTICE

A Simple Cupola Blast Volume Gauge. J. K. Smithson. (Foundry Trade Journal, 1935, vol. 53, Nov. 28, p. 398). The input of air to the cupola has a very great influence on the rate of melting, the coke ratio, the tapping temperature and general efficiency of the furnace. The blast volume may be simply measured by a Pitot tube in conjunction with a differential pressure gauge. In essence, the Pitot tube consists of two parts: a straight tube to measure the static pressure, and a bent tube to measure the sum of the velocity pressure and static pressure. A differential air gauge connecting the tubes enables the velocity pressure to be determined, from which the air delivery may be calculated. The author also describes a modification of the device in which both the total and velocity pressures are recorded.

The Control of Cupola Operation. H. L. Campbell and J. Grennan. (Iron Age, 1935, vol. 136, Dec. 19, pp. 18–23, 84, 86). The authors analyse the reactions which occur in each of the four zones of the cupola and classify the combustion conditions into eleven groups according to the proportions of carbon monoxide and carbon dioxide present in the stack gases. Data giving the air required to burn 1 lb. of coke in each case are given, the weight of iron melted and superheated to each of three temperatures per pound of coke is furnished, and the original and operating heights of the coke bed for different air pressures are presented. Attention is then given to the method of finding the weight of coke in each charge, the weight of metal and the amount of flux to be used. It is shown that the power required to deliver air to the cupola, and the amount of coke consumed, vary with the speed of melting. The authors do not consider it necessary to decrease the size of the tuyeres or alter the furnace lines in order to secure penetration of air to the centre of the cupola.

Metallurgical Progress in the Foundry. S. E. Dawson. (Institute of British Foundrymen: Foundry Trade Journal, 1935, vol. 53, Nov. 7, pp. 341–342). The author reviews certain of the more recent metallurgical advances relative to the production of cast iron in the cupola. He adduces evidence from independent sources to show that the quality of the materials charged into the cupola greatly affects the quality of the resultant iron; this effect persists even when the iron is remelted. The influence of finely dispersed silicates in the iron, and of general cupola practice is also mentioned.

Cupola High-Test Cast Iron. R. P. Lemoine. (Transactions of the American Foundrymen's Association, 1935, vol. 42, pp. 745–755). Recent developments in France in the production of high-

test cast iron have been along two lines. The first is the production of cast iron from low-carbon pig iron and steel scrap (the pig iron was formerly made in special blast-furnaces) and the use of the soda-ash treatment. The second development concerns the effect of ladle additions on graphitisation. The chemical requirements of high-test low-carbon cast iron are set forth and the use of ladle additions such as silico-calcium, silico-chromium, and silico-titanium is examined. Finally, directions are given for the manufacture of the special pig iron and of the ultimate product, high-test cast iron.

Some Properties of Mould and Core Materials at Elevated Temperatures. F. Hudson. (Institute of British Foundrymen: Foundry Trade Journal, 1935, vol. 53, Dec. 5, pp. 411–416). An account of experiments carried out to determine the effect of heat on the permeability, expansion, and compressive strength of five types of sand is given. The five sands were a steel foundry "compo" or proprietary mixture, an iron foundry green sand, an iron foundry dry sand, an oil sand, and a brass foundry green sand. The permeabilities of these materials were observed to decrease with increase in temperature. This decrease is mainly due to the effect of gaseous expansion, and is not the result of any pronounced structural change in the sands themselves. The expansion of the sands on heating was of a magnitude sufficient to warrant serious attention; the degree of expansion markedly increased between 500° and 700° C. The strength of the sands was generally increased to a considerable extent by heating up to about 900° C., but dropped suddenly beyond this point. The strength of the iron foundry green sand remained practically constant throughout the range employed, while that of the oil sand fell off to zero at about 400° C. Apparently the presence of coal dust in the iron foundry green sand tends to stabilise the strength. On correlating the results it is seen that the sands which expand most are also most subject to increase in strength at elevated temperatures—a circumstance which is probably responsible for many defective castings. The cost of fettling depends largely on the strength of the sand after cooling from elevated temperatures; experiments in this direction were conducted, and here again coal dust was found to prevent any fritting and consequent rise in strength. It is suggested that if the results of these experiments are considered in conjunction with the known temperatures attained in sand moulds, important improvements in foundry technique may become possible.

The American Foundry Industry. E. Piwowarsky. (Giesserei, 1935, vol. 22, Oct. 11, pp. 511–514; Oct. 25, pp. 536–539; Nov. 8, pp. 561–564). The author gives short notes on methods of testing foundry sand employed in America and of a visit to a number of malleable iron foundries and ferrous and non-ferrous foundries.

The Testing of Moulding Materials for their Strength during Casting by Means of Test Specimens for Iron, Steel, Malleable Iron, and Non-Ferrous-Metal Foundries. L. Treuheit. (Giesserei, 1935,

vol. 22, Dec. 6, pp. 601–603). The author describes a method of investigating the suitability of foundry sands and core materials for the purposes for which they are going to be used and their effects on the quality of the castings to be made. He presents two designs, one corresponding to thick sections and the other to thin sections, of test castings to be made. They consist of a vertical flanged cylinder with four longitudinal ribs outside; the ribs are of different sections and the flange thickness varies to match them, and the thickness of the cylinder wall also varies circumferentially. The moulds can be prepared by any of the processes used in the moulding shop and can be filled by top, bottom, or tangential pouring. Thus, by examining castings of the metal to be used made in a mould prepared with the mould and core materials to be tested, the foundryman can obtain full information regarding the suitability of these materials for the founding conditions (method of moulding, mode of pouring, temperature of casting, mould dressing, rate of cooling, &c.) to be used and the quality of the castings (limiting section thickness, density, surface condition, &c.) that will result.

Contribution on the Use of Cement Sand in Steel Moulding Practice. A. Gottwald. (Giesserei, 1935, vol. 22, Dec. 6, pp. 603–604). At a steel foundry in China possessing a 1-ton electric furnace, tests have been made on the use of cement-sand mixtures for making the moulds (the normal materials not being readily available). It was found that with a mixture of 100 parts (by weight) of a white sea sand (obtained locally), 13 parts of Portland cement, and 10 parts of water, perfectly good steel castings with a smooth surface could be made; it was equally satisfactory with acid and basic steel, plain or alloyed, and was particularly well-suited for castings of hard manganese steel, and has been used also for grey-iron castings such as piston rings and cylinders. The mode of using the mixture is described.

Foundry Machines. U. Lohse. (Zeitschrift des Vereines deutscher Ingenieure, 1935, vol. 79, Nov. 2, pp. 1337–1340). A brief review of sand-preparation, moulding, core-moulding, and cleaning machines used in the foundry.

The Sand Preparation Plant. G. E. France. (Sheffield Trades Technical Societies: Iron and Steel Industry, 1935, vol. 9, Oct., pp. 17–20). The conditioning of moulding sand has not in the past received the attention its importance in the foundry merits. In recent years, however, sand preparation has been more closely studied, and there are now available several types of sand-conditioning machines. In modern foundries the used sand is screened to free it from scrap iron and foreign matter, de-dusted to remove silt, and sent to a magnetic separator for extracting the finer particles of iron. The sand is stored in hoppers, as basis sand. To the basis sand are added the correct quantities of new sand and coal dust, and the charge is fed to the sand-mixing machine, where it is blended with water; the mixed and conditioned sand is then sent to the

moulding stations. The above description applies to facing sand, but backing sand, loam, and ordinary core sand are processed in a similar way. A separate plant may be used for preparing oil-bonded sands. The adoption of sand-conditioning plant enables considerable labour and material economies to be effected; if mechanised handling and transport are also employed, still larger savings are possible.

The Economics of Plywood in Patternmaking. R. Löwer. (Giesserei, 1935, vol. 22, Dec. 20, pp. 630–633). By means of several examples the author shows that the use of plywood in patternmaking can lead to considerable economy, provided that it is employed in suitable places.

The Qualitative and Quantitative Estimation of Sulphite Waste Liquor. F. Roll. (Giesserei, 1935, vol. 22, Dec. 20, pp. 628–630). Sulphite waste liquor (from sugar refineries and cellulose works) is one of the materials used as a binder for cores and moulding sand in foundry work. The author discusses briefly the production, properties, and the qualitative and quantitative determination of this material.

Pouring Gates, Risers, and Feeder Heads, their Appropriate Use for the Production of Good Castings. F. Paschke. (Giesserei, 1935, vol. 22, Oct. 25, pp. 539–542).

The Story of the Ford Cast Crankshaft. E. F. Cone. (Metals and Alloys, 1935, vol. 6, Oct., pp. 259–263). The author traces the development of the cast crankshaft employed by the Ford Motor Co. on their V-8 automobile engines. (*See* Journ. I. and S. I., 1935, No. II., p. 372).

Scrap Steel Additions to Chill-Cast Iron Charges. H. Patsch. (Giesserei, 1935, vol. 22, Nov. 22, pp. 584–586). The basic assumption that the depth of chill in chill-cast iron is primarily dependent on the silicon content is untenable; besides the silicon content, the graphite residues present in the molten metal play an important part in the development of the chill depth. The author shows that the addition of scrap steel to the charge of metal to be chill-cast not only improves the mechanical properties, but also increases the depth of chill.

The Manufacture of Rolls for Rolling Mills. (Engineer, 1935, vol. 160, Nov. 29, p. 566 : Metallurgia, 1935, vol. 13, Nov., pp. 1–4). A short account of the production of " Adamite " rolls at the works of Messrs. R. B. Tennent, Ltd., of Whifflet Foundry, Coatbridge, Scotland, is presented. The alloy Adamite is made in two general forms, namely, as a steel-base alloy and as a cast-iron base alloy. The analysis of Adamite is not given, but it is stated to have a low phosphorus content, and chromium and nickel as the alloying elements. The steel-base metal is produced in a 50-ton open-hearth furnace, and the iron-base alloys in reverberatory furnaces, one of which is of 40 tons capacity. The rolls are heat-treated in an oil-fired furnace of 100 tons capacity.

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The Foundry of the British Northrop Loom Company. (Foundry Trade Journal, 1935, vol. 53, Oct. 31, pp. 333–334). The foundry of the British Northrop Loom Company is equipped on modern lines for the production of castings varying in weight from a few ounces to 3 cwt., mainly for the loom trade. Among the principal items of equipment are the following: A sand slinger for ramming up the loom side castings (the adoption of which has greatly increased production); several roll-over jar and squeeze-jolt machines for repetition work; three magnetic-press machines, working on the principle of the movement of a core within an energised solenoid; a core-blowing machine; and an oil-fired rotary furnace for melting special irons.

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vol. 22, Dec. 6, pp. 601–603). The author describes a method of investigating the suitability of foundry sands and core materials for the purposes for which they are going to be used and their effects on the quality of the castings to be made. He presents two designs, one corresponding to thick sections and the other to thin sections, of test castings to be made. They consist of a vertical flanged cylinder with four longitudinal ribs outside; the ribs are of different sections and the flange thickness varies to match them, and the thickness of the cylinder wall also varies circumferentially. The moulds can be prepared by any of the processes used in the moulding shop and can be filled by top, bottom, or tangential pouring. Thus, by examining castings of the metal to be used made in a mould prepared with the mould and core materials to be tested, the foundryman can obtain full information regarding the suitability of these materials for the founding conditions (method of moulding, mode of pouring, temperature of casting, mould dressing, rate of cooling, &c.) to be used and the quality of the castings (limiting section thickness, density, surface condition, &c.) that will result.

Contribution on the Use of Cement Sand in Steel Moulding Practice. A. Gottwald. (Giesserei, 1935, vol. 22, Dec. 6, pp. 603–604). At a steel foundry in China possessing a 1-ton electric furnace, tests have been made on the use of cement-sand mixtures for making the moulds (the normal materials not being readily available). It was found that with a mixture of 100 parts (by weight) of a white sea sand (obtained locally), 13 parts of Portland cement, and 10 parts of water, perfectly good steel castings with a smooth surface could be made; it was equally satisfactory with acid and basic steel, plain or alloyed, and was particularly well-suited for castings of hard manganese steel, and has been used also for grey-iron castings such as piston rings and cylinders. The mode of using the mixture is described.

Foundry Machines. U. Lohse. (Zeitschrift des Vereines deutscher Ingenieure, 1935, vol. 79, Nov. 2, pp. 1337–1340). A brief review of sand-preparation, moulding, core-moulding, and cleaning machines used in the foundry.

The Sand Preparation Plant. G. E. France. (Sheffield Trades Technical Societies: Iron and Steel Industry, 1935, vol. 9, Oct., pp. 17–20). The conditioning of moulding sand has not in the past received the attention its importance in the foundry merits. In recent years, however, sand preparation has been more closely studied, and there are now available several types of sand-conditioning machines. In modern foundries the used sand is screened to free it from scrap iron and foreign matter, de-dusted to remove silt, and sent to a magnetic separator for extracting the finer particles of iron. The sand is stored in hoppers, as basis sand. To the basis sand are added the correct quantities of new sand and coal dust, and the charge is fed to the sand-mixing machine, where it is blended with water; the mixed and conditioned sand is then sent to the

moulding stations. The above description applies to facing sand, but backing sand, loam, and ordinary core sand are processed in a similar way. A separate plant may be used for preparing oil-bonded sands. The adoption of sand-conditioning plant enables considerable labour and material economies to be effected; if mechanised handling and transport are also employed, still larger savings are possible.

The Economics of Plywood in Patternmaking. R. Löwer. (Giesserei, 1935, vol. 22, Dec. 20, pp. 630–633). By means of several examples the author shows that the use of plywood in patternmaking can lead to considerable economy, provided that it is employed in suitable places.

The Qualitative and Quantitative Estimation of Sulphite Waste Liquor. F. Roll. (Giesserei, 1935, vol. 22, Dec. 20, pp. 628–630). Sulphite waste liquor (from sugar refineries and cellulose works) is one of the materials used as a binder for cores and moulding sand in foundry work. The author discusses briefly the production, properties, and the qualitative and quantitative determination of this material.

Pouring Gates, Risers, and Feeder Heads, their Appropriate Use for the Production of Good Castings. F. Paschke. (Giesserei, 1935, vol. 22, Oct. 25, pp. 539–542).

The Story of the Ford Cast Crankshaft. E. F. Cone. (Metals and Alloys, 1935, vol. 6, Oct., pp. 259–263). The author traces the development of the cast crankshaft employed by the Ford Motor Co. on their V-8 automobile engines. (*See* Journ. I. and S. I., 1935, No. II., p. 372).

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Progressive Mechanisation. V. C. Faulkner. (Foundry Trade Journal, 1935, vol. 53, Nov. 14, pp. 363–368). An account of the highly mechanised foundry of Messrs. Newman, Hender and Co., Ltd., Woodchester, is presented. Two Whiting cupolas are used, operated on three standard mixtures. Chief interest centres on the sand-preparation, core-making, and moulding equipment. Conveyors transport the cast moulds to the knock-out, and the subsequent handling of the sand is also on the conveyor system, leading finally to hoppers serving the moulding machines. There are ten of the latter, and they are supplied with moulding boxes by a roller conveyor from the shake-out. The core department deals with some 60,000–80,000 cores a week, and this also is fully mechanised. The core-drying ovens are heated by clean CO_2 gas; carbon monoxide is first generated in a producer and converted to CO_2 by a forced air supply in a secondary combustion chamber. The hot gas from the producer is circulated in the ovens, which are thus maintained at an even temperature of about 450–500° F.

From Liquid to Solid. W. Machin. (Iron and Steel Industry, 1935, vol. 9, Oct., pp. 6–7). The fact that castings contract on cooling, and that, if restrained, this contraction gives rise to severe stresses, is emphasised. It is pointed out that for this reason cores should be collapsible, or sufficiently compressible to enable contraction to take place.

Blow-Holes in Castings with particular Reference to Cast Steel. Knipp. (Giesserei, 1935, vol. 22, Oct. 11, pp. 505–511). The mode of occurrence and the behaviour of blow-holes in molten metals are discussed. Gases from the metal as well as those from the moulding materials can set up very fine needle-like channels in the casting skin connected to extended pin-holes; further, the gases entering and leaving the metal can have the same effect. In this respect the cooling conditions of the metal in the mould have a considerable influence. Blow-holes are not necessarily found in the neighbourhood of their formation in the casting; as a result of the flow of the metal, they may travel round within the mould and become enclosed in the freezing metal at some quite different place. This behaviour of blow-holes is exemplified by reference to a typical casting. The mass used for strickle-moulding in the steel foundry and facing materials are dense and also give off large volumes of gas; moulds made with such materials should be dried at not less than 500° C. Blow-holes in tensile test-pieces, even though they may be so small as to be invisible to the naked eye, diminish the strength properties.

PRODUCTION OF STEEL

(Continued from pp. 17A–23A)

Corby Iron and Steel Works. (Engineer, 1935, vol. 140, Nov. 1, pp. 449–451; Nov. 8, pp. 474–476; Nov. 15, pp. 509–510; Nov. 22, pp. 539–540). An illustrated description of the Corby Works of Messrs. Stewarts and Lloyds, Ltd., is given. (*See* p. 17A).

New English Ironworks at Corby. (Stahl und Eisen, 1935, vol. 55, Nov. 14, pp. 1214–1219). Brief notes on the ore winning and preparation, blast-furnace plant and operation, gas cleaning, blast heating, coal dressing and coke-oven plant, basic Bessemer plant, soaking pits, rolling mills, water supply and auxiliary plant at the Corby Works of Stewarts and Lloyds, Ltd., are given.

The Ural-Kusnetz Metallurgical Works (U.S.S.R.). J. Vichniak. (Génie Civil, 1935, vol. 107, Nov. 30, pp. 507–513). After reviewing general developments under the First and the Second Five Years Plans, the author turns to the Ural-Kusnetz "Combine," touches on the development of the Ural iron and steel industry before the war, and then describes, with illustrations, the iron and steel works at Kusnetz; brief reference is also made to the plant at Magnitogorsk.

The Evolution and Development of Steelmaking Processes. J. T. Wright. (Staffordshire Iron and Steel Institute, Sept. 24, 1935: British Steelmaker, 1935, No. 7, Dec., pp. 343–351). The author commences by describing the methods employed for making the Hindoo Wootz steel and the famous blades of Damascus, and then gives an account of the genesis of the steelmaking industry in Great Britain, and its subsequent development.

Improving Open-Hearth Furnace Design. W. C. Buell, jun. (Steel, 1935, vol. 97, Nov. 25, pp. 47–55; Dec. 2, pp. 50–53; Dec. 9, pp. 38–40). In the first article the actual construction of valves and their seatings are further described, and data relating to the size, type, and gas velocities of typical air, gas, stack, and waste-heat boiler valves are furnished. The subsequent articles deal with the design, construction, operation, and fuel economy of waste-heat boiler installations. (*See* p. 18A).

Evolution of Modern Methods of Refining Steel. Perrin. (Seventh International Congress on Mining, Metallurgy and Applied Geology, Paris, Oct. 20–26, 1935: Revue de Métallurgie, Mémoires, 1935, vol. 32, Oct., pp. 466–468). The author deals with the economic and technical advantages of the Perrin process of de-oxidising steel.

The Melting of Ferro-Manganese in the Tar-Oil Furnace. J. Haag. (Stahl und Eisen, 1936, vol. 56, Jan. 9, pp. 40–47). The author discusses the advantages of the use of molten ferro-man-

ganese instead of the solid material in steelmaking; the properties of the alloy; the melting of ferro-manganese and the slag manipulation; the properties of tar and tar-oil as fuel; the construction of the burners and the fuel consumption; the construction and lining of the furnace; and a comparison of the prime costs of tar- and tar-oil-fired furnaces, electric furnaces and preheating furnaces. The use of molten ferro-manganese leads to great economies in manganese, simply by decreasing the manganese loss and increasing the exactness with which the manganese content desired in the finished steel can be attained; wherever possible, therefore, the material should be added in the liquid condition. The author explains the causes of the difficulties encountered in the tar-oil melting of ferro-manganese and the precautions necessary for trouble-free operation. With the advantage of cheap installation costs, the melting costs with tar-oil-firing are no higher than for the electric furnace.

The Oxygen Pressure of Ferric-Oxide/Ferrous-Oxide Melts. W. Krings and H. Schackmann. (Zeitschrift für Elektrochemie, 1935, vol. 41, pp. 479–487: Stahl und Eisen, 1935, vol. 55, Dec. 19, pp. 1541–1543). The authors present and discuss composition/oxygen-pressure curves for various temperatures of mixtures of ferrous and ferric oxides, ferric oxide and lime, and ferric oxide and silica, and also curves in which the oxygen pressure is related to the free-oxygen contents of the melts. The thermodynamics of the cases are also considered.

REHEATING FURNACES

(Continued from pp. 24 A–25 A)

A New Ingot Heating Furnace. (Iron Age, 1935, vol. 136, Nov. 21, pp. 34–35). A description of a new ingot heating furnace installed at the Campbell Works of the Youngstown Sheet and Tube Co. is presented. The furnace is a circular pit, 7 ft. deep and 11 ft. in dia. at the top, lined with firebrick backed with insulating brick. The circular cover is suspended from a trolley equipped with mechanisms for raising and lowering and traversing the cover, which is sealed in a sand trough. The pit is fired by gas burners arranged to use a mixture of blast-furnace, coke-oven, and natural gas; the burners are set tangentially through the wall at the bottom of the pit, which is here wider than the top, thus avoiding the direct impingement of the flame on the ingots. The gases exhaust through a port in the centre of the furnace bottom to a short stack, and no regenerators are used. The temperature of the furnace, and the air/gas ratio, are automatically controlled by a recording pyrometer. Among the advantages claimed for this type of furnace are an absence of corners (and consequent cold ingots); a minimum pit depth, owing to the method of firing; uniform temperature; reduced radiation losses through the pit opening; and good control of the atmosphere, temperature, and fuel/air ratio.

Controlled Protective Atmospheres for Furnace Use. A. R. Ryan. (Industrial Heating, 1935, vol. 2, Nov., pp. 633–640). After stressing the need for protective atmospheres in furnaces, the author discusses the behaviour of iron and iron oxide when subjected to the action of protective gases such as hydrogen, carbon monoxide, &c., at high temperatures. He then touches on the influence of impurities in metals, the necessity of controlling atmospheres, the methods of purifying the gases (to remove water vapour), and the production of dissociated ammonia gas. Finally he briefly describes the combustion-type furnace controller in which the gas is mixed with oxygen and partly burnt, the water vapour removed, and the partially burnt gas used as the furnace atmosphere.

FORGING, STAMPING AND DRAWING

(Continued from pp. 26 A–30 A)

Progress in the Knowledge and Operation of Processes of Plastic Deformation. E. Siebel. (Metallwirtschaft, 1935, vol. 14, Nov. 8, pp. 893–897). A review of literature on theory and practice of the shaping of materials by plastic deformation.

Grain Control in Precision Drop Forgings. R. W. Thompson. (Metal Progress, 1935, vol. 28, Oct., pp. 187–190, 194). The author discusses some of the advances in forging technique which have been made during recent years, and then considers the production of two articles—an alloy steel ring gear forging and a light connecting rod—in further detail, to illustrate his remarks. In particular, he notes the close control over forging temperature, scaling, decarburisation, and forging tolerances which is now so essential to the production of high-quality forgings.

The Production of 18–8 Stainless Wire. R. Saxton. (Wire Industry, 1935, vol. 2, Nov., pp. 369–371). The author discusses rolling, annealing, pickling, and wire-drawing practice in the production of stainless (nickel-chromium) steel wire.

Difference between Structures Shown by Cold Working. B. L. McCarthy. (Metal Progress, 1935, vol. 28, Aug., pp. 36–38). The author shows that the sorbite produced by patenting wires for wire-drawing differs materially from that which is obtained by tempering quenched spring wire. The former is actually a fine variety of pearlite, and is admirably suited to subsequent reduction by wire-drawing. The latter is really troostite; it is very hard and scarcely amenable to drawing operations.

ROLLING-MILL PRACTICE

(Continued from pp. 31 A–34 A)

Graphical Computation. F. M. Scharff. (Blast Furnace and Steel Plant, 1935, vol. 23, Sept., pp. 611–615). The author suggests that mathematical calculations may often be greatly simplified by employing nomograms, and cites illustrative examples taken from rolling-mill practice.

Composition Bearings for Roll Necks and other Purposes. H. M. Richardson. (Iron and Steel Engineer, 1935, vol. 12, Nov., pp. 5–8). In this article some of the problems connected with the application and use of composition bearings are examined. Of the factors which affect the efficiency of the bearings, the temperature, amount, and purity of the water used for lubricating and cooling the bearings are perhaps the most important. At high temperatures the coefficient of friction increases, probably owing to breakdown of the film of water; if a sufficiently copious supply is used, however, the temperature may be allowed to rise to 113° F. Acids or salts in the cooling water tend to corrode the roll neck surfaces, especially if the temperature rises above 90° F. The addition of mineral oil, to the extent of about 2½%, helps to stabilise the water film. The amount of water required for the dual purpose of cooling and lubricating the bearing depends on the heat generated, the variation in duty (load and speed), the amount of heat transmitted to the roll necks, and the efficiency with which the water carries away the heat. Owing to their greater resilience, composition bearings tend to "give" under load or when being adjusted, more than do metallic bearings—a fact which must be borne in mind when the latter are replaced by the former. Composition bearings may be used for other purposes besides roll necks (table rolls, centrifugal pumps, line shafts, &c.); for these applications the means of lubrication depends on the duty which the bearings are to perform.

Composition Bearings. Recent Progress in their Use. K. T. MacGill. (Iron and Steel Engineer, 1935, vol. 12, Nov., pp. 9–11). After pointing out that composition bearings are now in use in almost every type of rolling-mill application, the author discusses some of the matters which, if not attended to, may give trouble. They relate to the purity, quantity, and temperature of the water, and the correct adjustment and alignment of the bearings.

Laminated Bearings. Their Use in Different Types of Rolling Mills. H. F. Horne. (Iron and Steel Engineer, 1935, vol. 12, Nov., pp. 12–13). The author presents brief notes on the application of laminated bearings of the impregnated fabric type to rod, merchant, strip, bar and billet mills, blooming mills, and hot sheet mills.

Oil-Flooded Bearings. Uses in Steel Rolling Mills. J. H. Hitchcock. (Iron and Steel Engineer, 1935, vol. 12, Nov., pp. 14–16). An account of the Morgoil type of bearing and its application to rolling-mill practice is presented.

Pressure Oiling System for Rolling-Mill Bearings. (Engineer, 1935, vol. 160, Dec. 13, pp. 628–629). An account of the oil-filtering system evolved by the Stream-Line Filter Co., Ltd., for the lubrication of rolling-mill bearings is presented. The main components are a storage tank, a pressure tank, filters, pumping machinery, and the oil-pipe mains, drain lines, fittings, and supports. The oil returned by gravity from the mill enters the storage tank, where purification by settling is effected; it first flows through a compartment fitted with heating coils thermostatically controlled so as to maintain a temperature of 100° F., thence to settling compartments, and so to the circulating pumps, delivering to the pressure tank. In this tank a cushion of compressed air at 25–40 lb. per sq. in. is maintained, which forces the oil to the bearings; should the pumps fail, the pressure tank is capable of maintaining the oil flow for several minutes. Purification of the oil is accomplished by three different processes; in the first, coarse impurities and entrained water are removed by settlement; in the second some 10% of the flow is by-passed through a bag-type filter which removes a large proportion of the finer impurities; thirdly, a relatively small percentage of the flow is by-passed through a stream-line edge filter of the Hele-Shaw type.

Output Supervision of an Ingot and Rail Mill. K. Skroch. (Stahl und Eisen, 1936, vol. 56, Jan. 2, pp. 10–14). After a brief description of the ingot and rail mill in question, the author deals with time studies of the various items of the plant. It is shown that the soaking pit plant constitutes the bottleneck. By means of an example, the author then shows how the output supervision of the ingot mill is carried out. All the calculations required are much simplified by the use of a nomogram. The time supervision could be simplified still further by measuring the net rolling time. The output supervision of the rail mill is effected in the same way.

Minimising Gauge Variations in Light Sheets. (Sheet Metal Industries, 1935, vol. 9, Nov., p. 693).

Ford Completes Hot Strip Mill and Cold-Finishing Mill. (Iron Age, 1935, vol. 136, Nov. 28, pp. 19A–19H, 80). **Modern Wide Strip Mill at Ford Plant has many New Features.** (Steel, 1935, vol. 95, Dec. 16, pp. 30–36, 56). New equipment for the hot- and cold-rolling of strip has recently been installed at the Dearborn (Michigan) plant of the Ford Motor Co. The hot mill is designed to produce strip in gauges as light as No. 18 and in widths up to 48 in. The cold mill delivers strip up to 78 in. wide and from No. 15 to No. 25 in gauge. The hot strip mill contains the following major units: A 44-in. blooming mill; a 1000-ton slab shear and gauging table; a 24 × 56-in. two-high scale breaker, followed by a 42 × 96-in.

two-high broadside vertical edger, and a two-high roughing mill vertical edger, 32 × 56 in.; a four-high roughing mill vertical edger, and a four-high roughing mill, each 21 × 46 × 56 in.; a two-high scale breaker, 24 × 56 in.; and five stands of four-high finishing mills, 21 × 46 × 56 in. There is also the necessary auxiliary equipment, including run-out and cooling tables, coilers, flying shears, and pilers; a special manipulator for the blooming mill is another feature of interest. The mills—with the exception of the blooming and roughing units—are fitted with anti-friction bearings throughout. Two slab reheating furnaces are in use, one of which is equipped with a tile recuperator and the other with a carborundum tubular recuperator. The change in temperature between the front and back of the strip as it passes through the finishing train tends to produce variations in the gauge; to correct this an air table has been put down. It is in sections, automatically controlled, each section consisting of a system of high-pressure air jets arranged above and below the table. After leaving the coilers the strip passes to the pickling tanks; the ends of the coils are stitched together so that the strip may be passed through the tanks continuously. The cold-rolling department handles wider strip than is produced in the hot mill, and the raw material is therefore purchased in the open market. The cold-rolling section consists principally of three four-high stands of 56-in. rolls, arranged in tandem, a four-high 84-in. reversing mill, and two stands of tempering or skin-pass mills 56 in. wide. As in the hot mill, these units also are fully equipped with roller bearings. The coils, before being temper-rolled, are annealed in a continuous electric furnace 48 in. wide and 227 ft. long. Material for deep-drawing operations is annealed in electrically heated coil annealers. Other features of the new plant are the housing arrangements for the mill motors (the blooming, hot-strip, and cold-strip mills have special motor rooms), and the comprehensive centralised lubricating system.

New Carnegie-Illinois McDonald Strip Mill. (Iron Age, 1935, vol. 136, Dec. 19, pp. 28–30). An account of the recently completed continuous strip mill of the Carnegie-Illinois Steel Corp. at McDonald, Ohio, is presented. The mill is designed to produce strip steel up to 37 in. wide and ranging in thickness from No. 18 gauge to $\frac{3}{8}$ in., and has a capacity of 30,000 tons a month. The main mill units are as follows: A horizontal two-high scale breaker, a slab reducer, three two-high roughing stands with one vertical edger, a four-high roughing stand with vertical edger, six four-high finishing stands, and flying shears, pilers and coilers. The mill is served by three continuous-type heating furnaces, fired with natural gas, and with a capacity of 50 tons of slabs per hr. per furnace. Auxiliary equipment includes a batch pickling unit, a normalising furnace, a skin-pass mill, a squaring shear, roller levellers, and oiling equipment. Forty-six Selsyn devices are incorporated in the roll adjusting equipment.

HEAT TREATMENT

Cementation of Iron and Ferrous Alloys by Glucinum [Beryllium]. J. Laissus. (Revue de Métallurgie, Mémoires, 1935, vol. 32, Sept., pp. 401–422). The conclusion of a series of articles. (*See* Journ. I. and S. I., 1935, No. II., p. 418).

Metallic Cementation (V). Cementation of Some Metals by Chromium Powder. T. Kase. (Kinzoku no Kenkyu, 1935, vol. 12, July 20, pp. 357–369). The author has investigated the cementation of iron and nickel by means of chromium powder at various temperatures between 800° C. and 1300° C.

Metallic Cementation (VI). Cementation by Means of Silicon Powder. T. Kase. (Kinzoku no Kenkyu, 1935, vol. 12, Aug. 20, pp. 397–410). The author used pulverised commercial silicon in an investigation of the cementation of iron, nickel, and copper at temperatures between 500° C. and 1200° C.

Metallic Cementation (VII). Metallic Cementation by Means of Manganese Powder. T. Kase. (Kinzoku no Kenkyu, 1935, vol. 12, Oct. 20, pp. 478–483). The cementation by manganese (in the form of the pulverised commercial product) of iron, nickel, and copper at various temperatures between 600° C. and 1100° C., for 1, 2, 3, and 5 hr. was investigated.

Experiments on the Diffusion of Carbon, Silicon, and Manganese in Solid and Molten Iron. M. Paschke and A. Hauttmann. (Archiv für das Eisenhüttenwesen, 1935, vol. 9, Dec., pp. 305–309). By two methods the coefficient for the diffusion of carbon in solid iron was determined; for temperatures between 900° C. and 1250° C. the values given by the two methods agreed well. Though the experiments on the diffusion of manganese in solid iron were not very accurate, they showed that this element migrates more slowly than carbon. Owing to the great experimental difficulties in the experiments on the diffusion of carbon, manganese and silicon in molten iron, only approximate figures for manganese and silicon were obtained.

Case-Hardening and Heat Treatment in Salt Baths. C. Albrecht. (Engineering Progress, 1935, vol. 16, Dec., pp. 311–312). Brief notes on the use of salt baths in case-hardening and heat treatment are presented.

The Electrolytic Transference of Carbon in Solid Steel. W. Seith and O. Kubaschewski. (Zeitschrift für Elektrochemie, 1935, vol. 41, pp. 551–558). It is shown that, in a steel wire which is heated by a continuous current to about 1070° C., the diffusion of the carbon is dependent on the direction in which the current is flowing. The effect can be revealed by measuring the electrical conductivity of individual portions of the wire and by etching.

Electrolytic Cementation of Iron. E. H. Klein. (Zeitschrift des Vereines deutscher Ingenieure, 1935, vol. 79, Nov. 30, pp. 1435–1438). Electrolytic precipitates (deposits) appear to be deposited on the electrode in the form of very finely-divided particles. For this reason it would seem that the electrolytic deposition of carbon, which is possible from certain melts containing carbonates, should be particularly suitable for the cementation of iron. The author describes how such a process of carburisation may be developed, what conditions must be observed in carrying it out, and how the economy of the process must be assured. In his tests he has examined the suitability of the various alkali or alkaline-earth carbonates, with or without admixtures of chlorides from the points of view of melting point and decomposition temperature; the unsuitable ones are indicated. In the carburising material, there is a transient electrolytic separation of the alkali or alkaline-earth metal; this then reduces its own carbonate to carbon monoxide or carbon, which then functions as the carburising agent. The influence of the concentration of the carbonate, the current density, the time and the temperature was investigated and is reported; the uniformity of carburising was checked by milling small cuts in the materials. The carburising power of the carbonates was found to ascend in the following order: Potassium, sodium, lithium, barium carbonates. For commercial use, mixtures of barium carbonate and chloride, as near as possible in composition to the eutectic mixture with 43% by weight of barium carbonate are suitable. For dipping baths sodium carbonate can be used.

Carburising Practice. C. C. Hodgson. (Metal Treatment, 1935, vol. 1, Autumn No., pp. 127–131). This article deals with the selection of plant and equipment, the formation of the case, and the operations of solid carburising, gas carburising, and cyanide carburising. After pointing out that small cylindrical carburising boxes are the least likely to give trouble due to warping, the author critically examines the various materials used for carburising boxes, and goes on to discuss the carburising operation. He suggests that temperature is a more important factor than the strength of the carburising compound, and that closer packing of the articles to be treated may usually be adopted with advantage. Finally, brief references to the cyanide and gas carburising methods are made.

Progress in Nitrogen Case-Hardening. H. Sutton. (Metal Treatment, 1935, vol. 1, Autumn No., pp. 143–145). The author shortly refers to the history of nitriding, the design of modern nitrogen-hardening plant and its operation, nitriding steels and cast irons, and the applications of nitrided parts.

Reducing Spalling on Nitrided Dies. B. Thomas. (Metallurgia, 1935, vol. 13, Nov., pp. 23–25). In this article the author examines the problem of the spalling of nitrided dies and offers suggestions to overcome difficulties which arise from the presence of sharp

corners and angles. It is pointed out that although nitrided dies suffer from spalling at the corners, owing to double penetration, ordinary tool steel dies, on the other hand, suffer from wear at the corners, which means that they are sharp for only some 20% of the effective life of the die. Hence it is suggested that the corners of nitrided dies may well be radiused without detriment to the finished product; the radius of curvature should then be of similar magnitude to the depth of the nitrided case. In this way spalling, although not completely eliminated, is very largely reduced.

Nitricastiron Cylinder Sleeves. A. T. Colwell. (Iron Age, 1935, vol. 136, Dec. 19, pp. 31–33). Cylinder liners of nitricastiron are stated to be much more durable in service than liners of other materials; thus nitricastiron will give a life of 300,000 to 400,000 miles, compared with figures of 75,000 to 200,000 for alloy cast irons, and 25,000 to 30,000 for ordinary irons. The alloy for nitriding has the following composition: Graphitic carbon 2·31%, combined carbon 0·62%, phosphorus 0·058%, sulphur 0·029%, manganese 0·76%, silicon 2·69%, chromium 1·28%, vanadium 0·16%, molybdenum 0·24%, aluminium 1·01%. The sleeves are centrifugally cast, machined, and tinplated on the outside to prevent nitriding of this surface. They are nitrided at 950° F. for 65 hr., a case up to approximately 0·015 in. being obtained. A surface hardness of 800 to 1000 Brinell is attained.

Review of Oxidation and Scaling of Heated Solid Metals. (Department of Scientific and Industrial Research, H.M. Stationery Office, 1935). This review is mainly concerned with the mechanism and rate of oxidation and the structure of oxide layers in metals exposed to high temperatures, but the last two sections contain a description of the practical effects of oxidation and scaling together with the methods to be employed for its prevention. Section I., by U. R. Evans, deals with the theoretical aspects of oxidation; it contains a discussion of surface films, time-oxidation curves, the cracking of oxide films, and the stimulation of oxidation by atmospheric impurities. L. B. Pfeil and A. B. Winterbottom contribute the following section, on the constitution and formation of scale on ferrous alloys; the iron-oxygen equilibrium diagram, the microstructure of scale on iron and steel, the mechanism of scaling, and scale on alloy steels are among the aspects dealt with. Section III., by J. C. Hudson and T. E. Rooney, constitutes a summary of the work of various investigators on the quantitative aspects of the oxidation and scaling of iron and steel at elevated temperatures. Non-ferrous materials are dealt with in the section which follows, which is contributed by J. S. Dunn and F. J. Wilkins. The concluding sections, "Oxidation and Scaling of Ferrous Metals from an Industrial Point of View," by S. A. Main, and "Practical Aspects of the Oxidation and Scaling of Non-Ferrous Alloys," by L. B. Pfeil, are concerned with the practical considerations which arise, as in the use and manufacture of iron and steel, in the applica-

tion of nickel-chromium heat-resisting alloys and of various non-ferrous alloys.

The Scaling of Mild Steel in Sulphur-Free and Sulphur-Containing Furnace Atmospheres. H. C. Millett and J. W. Cobb. (Institution of Gas Engineers, 1935. Communication No. 127). In this report on the above subject the authors begin with references to the general problem of scaling by furnace gases; they then proceed to give the results of an investigation carried out by them on the influence of temperature, period of exposure, gas velocity, and the composition of the furnace atmosphere on the scaling of mild steel, with special reference to sulphur. Among their conclusions are the following: At a certain critical gas velocity (dependent on the temperature, surface area and furnace atmosphere) the scaling decreases rapidly with the gas velocity; the addition of small amounts of sulphur dioxide to a neutral furnace atmosphere produces a rapid increase in the amount of oxidation and introduces sulphur into the metal and the scale; as the concentration of sulphur dioxide is increased the scaling is also increased, but at a diminishing rate; scaling increases with the temperature and time; the addition of free oxygen to neutral atmospheres increases the scaling, whether sulphur is present or not; scaling may be diminished by adding free hydrogen or carbon monoxide, although large quantities of gas are required.

The Influence of the Air Velocity on the Scaling of Iron. W. Baukloh and O. Reif. (Metallwirtschaft, 1935, vol. 14, Dec. 27, pp. 1055–1057). The authors describe scaling tests on Armco iron in which the velocity at which the air travelled past the specimens, and the temperature to which the test-pieces were heated were varied. As the velocity was increased so the scaling increased up to a point, but thereafter it dropped very considerably to a practically constant value. The position of the maximum moved towards higher velocities as the temperature was raised. The authors suggest the following explanation: At very low velocities there is a deficiency of oxygen molecules in relation to the rate at which the reaction of oxidation can proceed, consequently an increase in the air velocity results in an increased rate of scaling; when the maximum in the curve is passed, however, the excess of oxygen causes the crystallisation of the scale to change in such a way as to form a more dense layer, and this reduces the rate of scaling.

The Influence of Special Additions on the Scaling of Steel. K. Kiwit. (Mitteilungen der Kohle- und Eisenforschung G.m.b.H., 1935, vol. 1, No. 2, July, pp. 9–28). Low-carbon alloys were prepared from Armco iron and additions of aluminium, beryllium, chromium, copper, manganese, molybdenum, nickel, phosphorus, platinum, sulphur, silicon, titanium, vanadium, and tungsten; the melts, weighing about 3 kg., were cast and (with two exceptions) forged down; small cylinders, 50 mm. long by 10 mm. in dia., were made and polished to 00 emery. Each specimen was suspended,

during the scaling process, from a hook attached to the loop by which a small quartz thimble, provided to catch the scale which fell off, was held. The specimens were scaled at 900°, 1000°, 1100° and 1200° C., and the influence of the various alloy additions was investigated. As a result of the formation of scale by diffusion, the individual layers were sharply defined from one another at the temperature of formation. The layers were analysed separately, and it was found that during the scaling the alloying elements, both " noble " and " base " metals, were enriched at the iron/scale interface. Protective layers were formed in alloys of aluminium, chromium, silicon (which raise the resistance to scaling considerably), titanium, beryllium, and vanadium (which raise it only slightly). Of elements less noble than iron, the effects of additions of manganese, sulphur, boron, molybdenum, tungsten, phosphorus, arsenic, and antimony on the scaling were also examined, and here again, with the exception of manganese, an enrichment at the iron/scale interface, as compared with the outer layer, was observed. The addition of a more noble metal (copper, nickel, platinum) did not improve the scaling resistance; in fact, with platinum the scaling increased. For the Fe–Cr–Ni system the fields of resistance to scaling at 1000° C. were delimited and the oxides which formed were determined. As in the case of corrosion, weakly scaling steels, with low alloy contents, were not found. The observed facts, particularly the arrangement of the foreign oxides during scaling, can only be explained by the assumption that during scaling the iron atoms migrate but not the oxygen atoms. In order that a protective scale may form, first the new crystal type must possess a low diffusion rate and hence solubility in ferrous oxide, and secondly a dense closed skin or coating, which also hinders the diffusion of iron, must form round the metal.

Decarburisation of Some Alloy Steels by Hydrogen. W. Baukloh and H. Guthmann. (Archiv für das Eisenhüttenwesen, 1935, vol. 9, Oct., pp. 201–202). Tests on the decarburisation of unalloyed steels and steels containing nickel, chromium, manganese, silicon, tungsten, molybdenum, vanadium, tin, and copper, in a current of hydrogen at temperatures between 700° and 1000° C. are recorded graphically. For unalloyed steel, as the carbon content increased so the rate of decarburisation also increased at temperatures above 700° C., but decreased at lower temperatures. No connection could be found between the constitutional diagrams of the alloys and the decarburisation. There appears to be a connection between the carbon content and the " most favourable " content of the alloying element. The greatest resistance to the action of hydrogen was offered by steels containing up to 0·9% of chromium.

Alloy Containers for Heat Treating in Liquid Baths. F. K. Ziegler. (Metal Progress, 1935, vol. 28, Oct., pp. 59–63). The factors which affect the useful life of containers for heat treating

in molten baths of salt, cyanide, or lead are as follows: The design of the container; the design of the furnace; the fuel used; the temperature; the length of the heating and cooling cycle; the composition of the metal of which the container is made, and its physical soundness. Examples of failures due to the neglect of these factors are cited. It is pointed out that well-radiused corners should be used with rectangular pots, and that hemispherical pots should preferably be adopted; that a narrow flange, supplemented by a separate flange ring, is likely to eliminate cracking at the flange; and that flame impingement, due to faulty furnace construction, may lead to severe local overheating and corrosion. Attention is also drawn to the danger of allowing molten salts to reach the combustion chamber, so destroying the pot. The alloys used for the containers are briefly referred to, and the occurrence of defects in alloy pot castings is touched on.

Controlled Atmosphere Applications to the Heating of Steel. T. B. Bechtel. (Iron and Steel Engineer, 1935, vol. 12, Nov., pp. 1–4). The author begins by explaining the requirements of modern practice in controlled atmosphere heating, and follows this introduction by a description of some of the applications of controlled atmospheres. He refers to continuous brazing, the annealing of cold-drawn and stamped products, bright hardening, and the annealing of hot-rolled products. Some space is then devoted to the equipment required for this type of work, and the author concludes that so far the electric furnace is the most suitable for use with controlled atmospheres.

Heat Treatment by Forced Convection. W. A. Darrah. (Metal Progress, 1935, vol. 28, Nov., pp. 55–60, 80). The author discusses the advantages, operating principles, and commercial applications of heat treatment by forced convection in which heat transfer is obtained by the continuous circulation of hot air.

The Heat Treatment of Molybdenum Steel. A. J. Herzig. (Industrial Heating, 1935, vol. 2, Oct., pp. 569–574). The author outlines the principles of heat-treating practice as applied to the heat treatment of molybdenum steels, and reproduces data relating to the treatment of molybdenum, chromium-molybdenum, nickel-molybdenum, nickel-chromium-molybdenum, chromium-silicon-molybdenum, manganese-molybdenum steels, and molybdenum high-speed steels.

The Heat Treatment of Structural Steels. H. Kallen and H. Schrader. (Zeitschrift des Vereines deutscher Ingenieure, 1935, vol. 79, Nov. 30, pp. 1439–1442). The authors present a review of the effects of heat treatment (quench hardening, precipitation hardening, patenting) and surface hardening (carburisation, nitriding, local quench hardening) on structural steels. Work-hardening is also referred to.

Cold Drawing Alloy Steel. R. Saxton. (Heat Treating and Forging, 1935, vol. 21, Sept., pp. 430–432). The author furnishes

notes on the heat treatment of alloy steels for wire-drawing and cold working.

Improved Vertical Hot Tube Annealers. L. Wilson. (Iron Age, 1935, vol. 136, Nov. 21, pp. 26–29: Industrial Heating, 1935, vol. 2, Nov., pp. 659–662, 667). A type of furnace is described which is similar to the bell-type electric furnace, except that the heating elements are gas-fired radiant tubes. The rectangular body of the furnace may be lifted from the base so that the charge may be placed upon the latter; a sand seal is provided to prevent air leakage. The radiant tubes are disposed vertically on the side walls of the furnace, and are 12 to 36 in number. Made of nickel-chromium alloy, the tubes are fitted with "core busters," or refractory star-shaped baffles, inserted in order to break up the gas flow and improve the heat transference. Most of the heat of combustion is concentrated at the lower ends of the radiant tubes, where the burners are situated, for this is where the heat is chiefly needed. The temperature may be automatically controlled by means of a throttling device. A corrugated steel inner cover serves to protect the charge from oxidation on cooling, when the furnace shell has been removed. Many of these radiant-tube furnaces are in successful operation in America, where they are employed for annealing steel sheets.

Reduces Defects in Steel Rails by Normalising. J. Brunner. (Steel, 1935, vol. 97, Oct. 21, pp. 32–34).

Heat Treatment of Spring Leaves. W. T. Donkin. (Industrial Heating, 1935, vol. 2, Nov., pp. 641–644, 648, 672). An account of the spring heat-treatment department of the Eaton Manufacturing Co., Detroit, Michigan, is given. The parts treated are spring leaves of the following composition: Carbon 0·63–0·68, manganese 0·70–0·90, phosphorus and sulphur 0·04 (max.) each, silicon 0·20–0·30, and molybdenum 0·15–0·25%. This alloy is known as Amola steel. The leaves are hardened in an oil-fired walking-beam furnace, in which eight burners are employed to give three control zones. On emerging from this furnace the leaves are formed and quenched, and are immediately tempered. There are three tempering furnaces, each 40 × 2 ft. and of the continuous conveyor type. They are heated by a gas-fired heater situated on the top of the furnace, the gases being circulated through the work chamber by a fan. In order to provide a tortuous path for the gases, the roof and floor of the work chamber are built in zig-zag fashion. The gases are always circulated at the same velocity; the temperature is controlled by varying the gas and air supply to the combustion chamber. This type of furnace is stated to be flexible and easily controlled. The conveyor consists of perforated slats carried on an endless chain. The springs are hardened from 1450° F. and tempered at 810° F. They are stated to be uniformly hard, 95% of them giving a Brinell number of 444.

Hardening Characteristics and other Properties of Commercial One-per-cent.-Carbon Tool Steels. T. G. Digges and L. Jordan. (National Bureau of Standards Journal of Research, 1935, vol. 15, Oct., pp. 385–407). Two commercial 1% carbon tool steels, of widely differing hardening characteristics, were selected for a detailed study of the relation between the initial structure prior to heating for hardening, and the austenitic grain-size and grain-growth, and also the critical cooling rates. These data made possible a direct comparison of the relation between the austenitic grain-size and the critical cooling rates over a range of quenching temperatures of 1425° to 1775° F. The steels were also compared with respect to their behaviour in the transformation temperature range during thermal analysis, the relative rates of spheroidisation of the cementite, the Charpy impact values, relative susceptibility to grinding cracks, Rockwell hardness values on quenching at different rates, structural normality, performance as lathe tools, and the effect of the rate of heating to the hardening temperature on the depth of hardening. For quenching temperatures below that at which all the carbon is dissolved in the austenite, both the austenitic grain-size and the critical cooling rates were found to be greatly influenced by the structure of the steels. Above this temperature, each steel approached both a grain-size and a critical cooling rate which were characteristic of the steel regardless of its critical structure.

Influence of the Method of Manufacture and of the Variations of Analysis on the Hardness Limits and Depth of Hardening of some Low-Alloy Steels. O. Hengstenberg and E. Houdremont. (Technische Mitteilungen Krupp, 1935, vol. 3, Nov., pp. 189–195). From a large series of investigations on steels the manufacture of which had been supervised continuously by determining the hardness limits and depth of hardening, the authors show, by reference to three selected types of steel, how these two factors depend on one another and what factors affect them. The carbon contents ranged about 0·5%; the steels were alloyed with small quantities of chromium-nickel-molybdenum, nickel, and chromium-nickel, respectively. They were made in the open-hearth (one acid, two basic), and the raw materials, and more particularly the methods of deoxidation, varied widely. Small specimens were cast and forged down; specimens of the bars so produced were heated and quenched from various temperatures, and then broken, the temperature producing the first signs of granularity in the fracture being noted; in other specimens the depth of hardening was observed. Finely-divided inclusions were found to decrease the depth of hardening, while the hardness range widened; some alloying elements, like chromium and molybdenum, increased the depth while reducing the range, while some, like silicon and nickel, increased both the depth and range. As the first two factors preponderated, in general intense hardening corresponded with a narrow hardness range. The investigation confirms the previously suggested connection

between the susceptibility to overheating engendered by large austenite grain-growth, and reduced depth of hardening.

The Quenching Power of Various Liquid Quenching Media. K. G. Speith and H. Lange. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1935, vol. 17, No. 14, pp. 175–184). The influence of the flow of the liquid and of the formation of a film of steam on the exchange of heat between the quenched article and the quenching liquid was observed in detail by means of photographs and in its entirety by taking quenching curves for a variety of media by thermo-electric means. That quenching proceeds in three stages at different rates was confirmed. At high temperatures the rate of cooling is controlled by the formation of a closed film of steam which restricts the cooling according to its thickness and the period for which it remains intact. In this stage the heat of vaporisation is of small influence; in the middle stage, however, when the film of steam collapses, it becomes of prime importance, and here also the more or less explosive character of the collapse of the steam film is important. In this middle range of temperatures the quenching power of the medium is at its greatest. In the third stage the removal of heat takes place more slowly by conduction and convection.

The alteration of the quenching power of water at various bath temperatures was investigated by adding various substances. The laboratory tests suggested that the quenching power could be influenced by additions of " pektinit "; this was confirmed by larger series of tests, but it was found that the temperature course during quenching was less favourable as compared with quenching oils, and also that the quenching power of " pektinit " solutions changed with repeated use and on standing a long while in the quenching vessel. " Pektinit " is a proprietary material; it consists principally of pectins (high-molecular, non-crystalline substances), mostly obtained from apples, citrus fruits, &c. The pectin lowers the cooling effect of the water according to the amount added; a 6–7% solution should have about the same cooling properties as the usual quenching oils.

Quenching Stresses. G. Wassermann. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1935, vol. 17, No. 13, pp. 167–174). X-ray stress measurements on quenched specimens of aluminium, duralumin, and iron showed that quenching set up compressive stresses at the surface. In general, specimens about 1 mm. in dia. were completely or nearly free from stress; as the diameter increased, the stresses increased, at first rapidly and then more slowly, finally reaching a maximum value. Further, the stresses rose with increasing quenching temperature, but the relationship was not always very clear. In mild steel stresses of up to 75 kg. per sq. mm. were produced, and here there was a marked relation to the quenching temperature. The conditions for the occurrence of quenching stresses are discussed, and also the possibility

of an influence of the stresses on age-hardening phenomena and on the lattice constants of quenched X-ray specimens. In regard to the various suggestions recently made that the magnitude of the lattice constants are dependent on the physical condition of the material, on the crystal size or on the degree of deformation, it is pointed out that these observations can be easily explained, at least in part, by the existence of quenching stresses.

The Tempering of High-Speed Steel. O. W. Ellis. (Metal Progress, 1935, vol. 28, Oct., pp. 85–87). The results of a co-operative experiment are recorded, in which specimens of tungsten-chromium-vanadium steel were sent to eight workers to be subjected to a common heat treatment, which was as follows : Heat slowly and uniformly in a preheating furnace to 1350° F. ; transfer to a furnace at 2350° F. and maintain this temperature for 3 min. ; quench in oil, noting the temperature of the oil used. Samples from the test specimens were then tempered (under uniform conditions) at various temperatures and for various times, and the hardness of each specimen was ascertained. The results are reproduced in the form of curves.

WELDING AND CUTTING

(Continued from pp. 35A–36A)

Modern Methods of Welding. C. H. Davy. (Institute of Chemical Engineers, Oct. 9, 1935: Welding Industry, 1935, vol. 3, Nov., pp. 352–355). The author outlines the salient features of the forge, oxy-acetylene, flash, atomic hydrogen, and metallic arc fusion welding processes, and indicates the class of work for which each is suitable and the extent to which each method is used. Space is also devoted to the questions of the electrode and the welding technique, and there is a concluding note on the effect of welding on the structure of the metal.

Arc Welding in Argon Gas. G. E. Doan and W. C. Schulte. (Electrical Engineering, 1935, vol. 54, Nov., pp. 1144–1149). The authors report the results of an investigation of metallic-arc welding in an atmosphere of argon gas. Welding was performed in a chamber supplied with argon and fitted with appliances for manipulating the work and the welding rod. Certain phenomena were found to be associated with welding in argon which differed strikingly from those observed in ordinary welding in air. Thus, a stable arc cannot be maintained in argon the purity of which exceeds 99·5% unless the open-circuit voltage is greater than 62 V. and the short-circuit current greater than 110 amp. While the melting rates in argon and in air are similar, the transfer of metal in argon occurs in the form of large globules about $\frac{7}{32}$ in. in dia. every 1 or 3 sec., whereas in air the globules are quite small and fall at the rate of 10–15 per sec. The globules in argon cross the arc under no apparent force except gravitation; the pinch effect is absent. The arc is calm and quiet, and no crater of liquefied base metal is seen to form—hence there is complete lack of penetration into the parent metal. When welding in a mixed atmosphere of 50% air, 50% argon, however, good penetration was obtained.

Electrical Characteristics of the Welding Arc. S. C. Osborne. (Journal of the American Welding Society, 1935, vol. 14, Nov., pp. 11–18). The author examines the electrical phenomena associated with the passage of the metallic arc stream during welding. The mechanisms of ionisation and thermionic emission are explained, and a description of the conditions at the cathode spot, within the arc stream, and at the anode, is furnished. Attention is also devoted to the energy distribution in the arc, the current and voltage conditions at "strike" and during welding, and voltage surges.

A New High-Frequency Arc Welder for Welding Thin Plate. W. A. Ankerson. (Metropolitan-Vickers Gazette, Oct., 1935: Welding Industry, 1935, vol. 3, Dec., pp. 390–392). The welding

type are susceptible to intergranular corrosion on welding, unless the welded parts are given a correcting heat treatment. The addition of titanium or columbium to stainless steels suppresses the tendency to intergranular corrosion, and obviates the necessity for subsequent heat treatment. The welding procedure is, in its essentials, the same as that used in gas-welding ordinary steels.

The Welding of Copper-Nickel-Molybdenum Steel. H. L. Miller. (Journal of the American Welding Society, 1935, vol. 14, Dec., pp. 28–30). Details of a high-tensile copper-nickel-molybdenum steel for welding into tanks for the transport of petrol and fuel oil are furnished. The steel has the following composition: Carbon 0·095, manganese 0·70, phosphorus 0·017, sulphur 0·028, silicon 0·03, copper 1·44, nickel 0·75, molybdenum 0·07%. An ultimate strength of 82,400 lb. per sq. in., combined with a yield point of 69,800 lb. per sq. in. and an elongation on 2 in. of 33%, are claimed. A stronger grade containing 0·25% of carbon is also made. Drop tests on the welded tanks show that they will withstand much hard usage, leading to considerable deformation, without failing at the welds. The use of this high-tensile steel enables a reduction in dead weight to be effected.

Fabricated Composite Dies. K. Janiszewski. (Journal of the American Welding Society, 1935, vol. 14, Nov., pp. 7–9). A method of fabricating composite dies is described, in which the body of the punch or die is cut from mild steel plate by the oxygen cutting flame and the working edges of the tools consist of rectangular bars or strips of tool steel attached to the periphery of the punch or die by means of welding. Since only a small machining allowance is needed, the cost of this operation is less than with tools cut from solid blanks. The working edges are of vanadium tool steel, which is subjected to the usual hardening treatment—a treatment which leaves the body of the die in the unhardened condition. These composite punches and dies are stated to possess advantages which include a saving in cost of from 30 to 50%, minimum machining time, less risk of cracking during hardening, and easier correction of distortion; salvaging and alteration are also less difficult to carry out.

Hard-Facing Materials and Methods. R. E. Brown. (Metals and Alloys, 1935, vol. 28, Oct., pp. 136–140, 144). After indicating the properties which it is desirable that a material for hard-facing should possess, the author classifies the materials in the following way: (1) Cheap alloys—generally high-carbon steels or cast irons—with unsatisfactory properties; (2) austenitic alloy steels, in which the total alloying elements do not exceed 20%; these are durable, tough, ductile, and not very expensive; (3) metals of high intrinsic hardness, containing between 20 and 50% of alloying elements; (4) non-ferrous alloys of the cobalt-chromium-tungsten type (stellite); (5) tungsten carbide, and similar materials; and (6) combinations of hard-facing alloy and crushed tungsten carbide.

The relative wear resistances of each group of materials are compared, and shown to be related to the red hardness. Attention is then directed to the welding methods suitable for hard-facing. Both the oxy-acetylene and electric arc systems may be used, but in any case it is desirable that the penetration into the basis metal shall be as small as possible compatible with adequate adherence. Stellite may be successfully applied by using a carburising oxy-acetylene flame; on the other hand, hard-facing applied to manganese steel requires the adoption of electric arc welding by a special technique. The author quotes many of the applications of hard-facing, including oil-well drilling bits, the tooth edges of excavators and coal cutters, grinding and crushing equipment, and valves and valve seatings.

Metals are Brazed in Controlled Atmosphere Electric Furnaces. H. M. Webber. (American Society for Metals, Apr. 15, 1935: Steel, 1935, vol. 97, Aug. 12, pp. 30–33; Aug. 26, pp. 36–38, 50). The early development of copper brazing is traced, and examples of modern brazed articles are cited. It is contended that electric brazing is cheaper and more reliable than pinning or riveting. The production of double-walled steel tubing from copper-plated steel strip is also mentioned. In the second instalment the mechanism of the brazing process is outlined. It is shown that if tight joints are made, adequate strength in the brazed article is developed. If necessary, the grain-growth in the steel which sometimes accompanies the brazing operation may be removed (and the original structure restored) by subsequent heat treatment. This applies more particularly to chromium-molybdenum and similar alloy steels. Both batch and continuous furnaces are suitable for the brazing operation, the mesh-belt type being especially adapted for the processing of small parts. Various reducing atmospheres may be maintained within the furnace; natural gas, coke-oven gas, propane or butane, previously subjected to partial combustion, are commonly favoured. Such a pre-burnt gas contains 20% of hydrogen, 12% of carbon monoxide, 3% of carbon dioxide, and the remainder nitrogen.

The Repair on Site of a 200-Ton Press. R. Meslier. (Bulletin de la Société des Ingénieurs Soudeurs, 1935, vol. 6, Aug.–Oct., pp. 1873–1879). The author describes the carrying out of repairs, without removing the machine, to a 200-ton press. The frame, a standard, and two large cast-iron gear wheels were damaged; they were all repaired by welding.

Prediction of Weld Performance. N. F. Ward. (Journal of the American Welding Society, 1935, vol. 14, Dec., pp. 11–15). This article is in two parts: Part I. consists of a general examination of the factors which influence weld performance; Part II. is an account of some tests on a model bulldozer in order to elicit the behaviour of the welds in the full-sized model. It is shown that to predict the performance of welds it is necessary first to pay attention to the materials, design, and welding technique. The use of welded

models requires that the model and prototype be statically and dynamically similar; given this condition it is possible to estimate the probability of premature failure or the existence of faulty design in the full-sized model. Details are given of some tests on a welded bulldozer model, and the modifications in design which were introduced as a result of the tests.

The Determination of the Quality of Welds and Electrodes. A. Neumann. (Welding Industry, 1935, vol. 3, Dec., pp. 372–376). The author remarks that certain tests performed on welds are of limited or doubtful value unless the full conditions of the test are specified. Thus, merely to state the tensile strength of a test-piece is insufficient; it is essential to give the elongation over a definite gauge length if the ductility, and hence the quality of the material, is to be assessed. In the same way, the impact value is highly dependent on the cross-section of the notched specimen, and this, too, must be specified. Malleability is often essential in a weld, yet it is particularly difficult to define adequately. The author enlarges on this last point, and describes a comprehensive scheme for testing the malleability of welds. Tests are carried out on single V butt-welded plate samples, and on samples of beads of deposited weld metal. The tests comprise (1) heating the butt-welded specimen, and hammering it down to a reduced cross-section, followed by twisting through several turns; (2) hot-bending a flat test-piece upon which weld metal has been deposited (the weld metal being in tension), the specimen being subsequently hammered flat and forged into a tongue at the bead; (3) hot-bending a butt-welded sample, which is then hammered flat. On the basis of these tests the welds are given a rating varying from 0 to 10, this rating constituting the " coefficient of malleability."

The Influence of Cold Deformation on the Welding Properties of Bare Steel Electrodes. A. Kessner and H. Specht. (Archiv für das Eisenhüttenwesen, 1935, vol. 9, Nov., pp. 231–239). Tests to determine the influence of cold-working (during manufacture) and subsequent annealing on the welding properties of bare electrodes intended for welding structural steels St 37 and St 52 were carried out; the electrodes for steel St 37 were made from open-hearth and electric steels, while those for steel St 52 were all of open-hearth steel; the rods had been drawn to three degrees of reduction and annealed. The losses by spattering, the specific gravity of the weld, the adhesion (in vertical welding), the form of the seam, and the penetration all depreciated with increasing cold deformation. The results of the " drop " test (droplets of metal are melted off the end of the electrode by a small oxy-acetylene flame; they fall from a given height on to a steel sheet, and their splashing is observed), frequently used in the works, bore no relation to the quality of the electrodes. In V-welds made with the electrodes under test, the tensile strength, elongation, and bending angle decreased with heavily drawn rods, and the structures were full of inclusions and pores and

were unsatisfactory; nevertheless, the notch-impact strength was higher. The loss of manganese and carbon in the arc and the absorption of oxygen and nitrogen by the weld metal were hardly affected by the cold-working of the electrodes. The chief cause of the variation of the welding properties of the rods was found to be that cold-deformation reduced their electrical and thermal conductivities; as a result the rate of melting-off of the rods increased and the electrodes became hotter during welding, and this led to the depreciation of the structures of the welds.

Thermal Study of Welds. A. Portevin and D. Séférian. (Chaleur et Industrie, 1935, vol. 16, Sept., pp. 409–424). This paper is divided into two parts. In the first, of a theoretical nature, the authors give consideration to the distribution of heat in the case of localised fusion at a fixed point between plates of infinite extent or between bars, and then examine the problem for the case where the zone of fusion is moved. The curves derived from the calculations represent the general course taken by the phenomena. In the second part the authors present their experimental results. The differences observed between theory and practice are explained by the approximations made in order to obtain a solution to the complex differential equations demanded by theory. The conclusions drawn from the experimental study demonstrate the influence of the process and the methods of welding, of the nature of the metal (its conductivity), and of the dimensions and shape of the pieces welded.

Methods of Minimising Distortion in Light Gauge Steel. J. H. Blaha. (Journal of the American Welding Society, 1935, vol. 14, Nov., pp. 18–22). The procedure adopted for minimising distortion during the welding of a refrigerator liner is described.

Further Investigations on the Self-Stresses in Simple Welded Joints. F. Bollenrath. (Archiv für das Eisenhüttenwesen, 1935, vol. 9, Oct., pp. 203–207). In two V-welds, made with bare and coated electrodes respectively, the shrinkage stresses (measured by two methods—by measuring the deformation of a bore-hole, and by observing the change of length of a strip removed from the weld) were found to be of equal magnitude. In a further ten welds, the influence of welding in sections on the reduction of the self-stresses, as compared with continuous welding, was investigated. By a suitable subdivision of the weld, the shrinkage stresses in the direction of welding, which attain their maximum at a weld length equal to about ten times the plate thickness, could be reduced to nearly one-third of those in a continuously-welded joint, while the cross-stresses remained the same. With thicker plates, X-welds gave smaller shrinkage stresses than V-welds.

Welding. Residual Stresses, Distortion, and Welding Procedure. H. W. Townshend and J. L. Adam. (Welding Industry, 1936, vol. 3, Jan., pp. 436–441). This article constitutes a critical commentary on the papers contributed to the Welding Symposium

dealing with the subjects of residual stresses, distortion, and welding procedure.

Overstressing in Welded Joints. H. Buchholz. (Welding Industry, 1935, vol. 3, Sept., pp. 267–271; Nov., pp. 337–339; 1936, Jan., pp. 415–419). The author points out that measurements of the dimensions of a welded part before and after welding do not enable the internal stresses to be evaluated, since the changes observed include the plastic deformations which occur during welding. However, by the use of the Mathar apparatus the internal stresses may be determined. This device enables the deformation in the region of a drilled hole to be measured, and consists of a small drilling machine with an extensometer attached; by its use the relation between the deformation and the drilling depth may likewise be ascertained. The author discusses the magnitude and incidence of the thermal stresses set up during welding; he suggests that the internal stresses in the direction of the weld are always greater than those transverse thereto, and that the wider the zone of heating, the smaller do the stresses in the weld become. He shows that the operation of welding always imposes stresses due to thermal expansion and contraction; these stresses may be very high, with the result that when additional (external) stresses are applied, overstressing occurs—particularly in the case of hindered deformation, which is the usual case met with. Under these conditions plastic deformation tends to set in, neutralising the local stress concentrations. The author also describes some tests which were performed on gas-welded specimens, in which the stresses in the test-pieces were measured before and after testing in a tensile testing machine. He concludes, on the basis of these results, that the weld metal and the material of the plate should have as far as possible the same mechanical properties, and, more especially, the same high yield point coupled with a marked extension at that point. But since welded joints of high ductility (at the yield point) and proportionate strength positively reduce the internal stresses (owing to the overstressing brought about by a single additional stress) the fatigue strength in such cases is not affected by internal stresses. The author distinguishes between (1) overstressing due to high internal stresses combined with externally applied stresses, and (2) overstressing arising from poor design or poor welding. In the latter case welding should be avoided, or else the weld metal should possess strength and ductility similar to that of the weld metal—this also applies to case (1); cracks and low fatigue strength are often occasioned by brittle weld metal. The wider the zone of heating, the smaller are the weld stresses set up, and the more severe the restraint the greater are the structural stresses induced.

CLEANING AND PICKLING OF METALS

Wooden Pickling Tanks. P. W. Bennington. (Steel, 1935, vol. 97, Dec. 2, pp. 30–34). Among the matters touched upon in this discussion of the design, construction, and maintenance of wooden pickling tanks are the following: The suitability of the types of timber available (yellow pine appears to be the most satisfactory); details of the construction, such as the joints used; materials for the tie rods, and their behaviour in service; and the features of a well-built tank.

Modern Acid-Handling Methods Lower Pickling Costs. J. R. Hoover. (Wire and Wire Products, 1935, vol. 10, Sept., pp. 407–410, 451). The disadvantages which attach to the operation of pickling plant (acid leakage, corrosion, high maintenance costs) are shown to be surmountable if suitable changes in technique are adopted. The use of a special tank lining material—Triflex—consisting of three plies of rubber, the two outer being soft and the inner one hard, is cited. The lining is bonded to the steel tank by the Vulcalock process, and protected from oxidation and mechanical damage by a brick sheathing. Waste pipes and sewers may be covered with the same material.

Acid Cleaning and Material Handling of Rods and Wire. F. A. Westphal. (Wire and Wire Products, 1935, vol. 10, Sept., pp. 401–405). In surveying the subject of the acid cleaning of wire rod the author deals with the temperature, acidity and specific gravity of the bath, the time required, the subsequent rinsing, sulling, liming and baking operations, and the effect of inhibitors in the acid bath. The author quotes several examples of the problems which arise in acid cleaning practice, and concludes with a short discussion of the materials used in acid vat construction.

PROPERTIES AND TESTS

On the Definitions of the Terms "Cast Iron" and "Steel." A. L. Norbury. (Bulletin of the British Cast Iron Research Association, 1935, vol. 4, July, pp. 157–163). The author suggests suitable definitions for steel, cast iron, malleable cast iron, pig iron, and refined pig iron, on the basis of the presence or absence of graphite or carbide eutectic. He recommends the abandonment of the term "semi-steel." The author cites extracts from technical and other sources on the definition of the above terms, and examines them critically. He concludes that definitions in terms of microstructure are the most satisfactory, and it is for this reason that the recommended definitions are based on structure.

The Testing of Engineering Materials. H. J. Gough. (Institute of Marine Engineers, Oct. 8, 1935, Preprint). In this paper the author discusses a number of aspects of the testing of engineering materials, many of which are of particular interest to the marine engineer. Attention is chiefly devoted to current or recently completed researches carried out at the National Physical Laboratory. The subjects treated include the following: Testing of materials at high temperatures (creep phenomena); high-tensile structural steels, particularly their behaviour under stress, compared with mild steel; lubrication; lifting gear, and especially the fatigue failure of components of such gear; contact corrosion; welded joints; the cracking of boiler plates, and the related phenomenon of corrosion fatigue; fatigue (including the effect of surface finish); the failure of metals under complex stress distribution; and failures in service.

The Problem of the Shape Factor. A. Thum and W. Bautz. (Zeitschrift des Vereines deutscher Ingenieure, 1935, vol. 79, Oct. 26, pp. 1303–1306). From the literature and from their own experiments, the authors have collated shape factors for a few simple shapes of notch in regard to stressing in tension, in torsion, and by bending. The utility and reliability of the individual curves are discussed critically, and data are presented of which the constructor can make use in his calculations.

Dynamic Elasticity of Metals. A. Leblanc. (Métaux, 1935, vol. 10, Sept., pp. 209–213). The author first discusses the mechanics of elastic extension under impact, then gives some values of the dynamic elasticity of several metals (including four steels) at various temperatures, and finally presents a graph relating the dynamic elasticity to the density for a number of alloys.

An Extensometer Comparator. A. H. Stang and L. R. Sweetman. (Journal of Research of the National Bureau of Standards, 1935,

vol. 15, Sept., pp. 199–203). An extensometer comparator for the calibration of extensometers, compressometers, micrometer dials, and strain gauges is described. The comparator consists of a frame with a fixed cross-head (to which is attached the measuring device) and carrying an adjustable crosshead. The small changes in length are recorded by an indicator such as a Zeiss optimeter or dial micrometer; the indicator is not used for the measurement of distances, however—standard gauge blocks are employed for this purpose.

Influence of the Elasticity of the Tensile Testing Machine on the Stress-Elongation Diagram. W. Späth. (Archiv für das Eisenhüttenwesen, 1935, vol. 9, Dec., pp. 277–282). A tensile testing machine is composed of a series of elastic parts and masses. In static tests, therefore, the shape of the stress-strain diagram is essentially dependent on the elasticity of the machine. The less "give" there is in the machine, the more sensitive is it to show up plastic deformations in the specimen with decreasing stress. With more "give," on the other hand, plastic deformation can occur under approximately constant stress. From this, conclusions are drawn regarding the lower yield point. In the observation of rapid flow processes the natural frequency of the various vibrating systems plays a decisive part. Principles for the further development of tensile machines are laid down and two types are distinguished—machines with much "give" and those with very little. The latter must be able to show a "lower yield point," not only for very coarse flow phenomena, but also on exceeding the elastic limit.

The Untenability of the Concept of the Upper and Lower Yield Points and the Breaking Stress of Soft Steel and Other Metals. G. Welter. (Metallwirtschaft, 1935, vol. 14, Dec. 20, pp. 1043–1047). The author presents critical considerations to show that the stress-strain diagram of soft steel and other plastic materials does not correspond to actuality. He says it is not conceivable that the stress should decrease at the upper yield point; similarly a reduction of stress from the maximum-stress limit till the specimen fractures, with increased contraction, is not possible. By means of laboratory tests, in which the specimens were stressed by the direct application of weights, he shows that soft steel does not possess an upper yield point, and that in plastic materials no decrease of the maximum-stress limit before fracture can be recorded. The diagrams produced by the ordinary tensile machines do not correspond to the actual properties of the materials and need considerable correction. The author suggests that tensile testing machines should be redesigned to work on the principle of the application of stress directly by weights.

International Standardisation of the Shape of the Specimen for Notch Impact Tests. R. Mailänder. (Stahl und Eisen, 1935, vol. 55, Dec. 5, pp. 1456–1458). A. Steccanella (Metallurgia Italiana, 1935, vol. 27, pp. 81–108) has carried out an extensive investigation

in which the scattering of the results given by the usual notched-bar impact-test specimens (10 × 10 × 55 mm.) with notches 2, 3, and 5 mm. deep (2 mm. wide in all cases) and the ability to differentiate between specimens were examined. The present author discusses these findings and, in part, presents them in a different form. The 2-mm. deep notch was superior only in its ability to differentiate, but only slightly so. The additional test-bar shape suggested in Germany, with a 1-mm. dia. notch, offered no advantage in the cases tested by Steccanella; its range of application should therefore be limited. Limiting and average values for the impact values obtainable with the three forms of bar are given.

Acceleration of a Structural Reaction in a Steel by the Effect of a Mechanical Stress. P. Chevenard and X. Waché. (Académie des Sciences, Oct. 28, 1935: Génie Civil, 1935, vol. 107, Nov. 30, p. 524). The authors demonstrate that mechanical stress can accelerate structural reactions, such as the coalescence of cementite, in steels. A low-carbon, chromium-molybdenum-vanadium steel was air-quenched, tempered, and tested under various loads at different temperatures. Next the specimens were submitted to the ordinary tensile test at room temperature; finally, test bars were prepared from these pieces for electrical, magnetic, micrographic, and dilatometric tests. Curves, for four temperatures of the hot test, show the permanent elongation of viscous origin in relation to the load applied, and also the cold tensile strength; the latter curves demonstrate that during the hot test the metal underwent softening, the extent of which depended on the amount of the flow. As none of the other tests revealed any appreciable physico-chemical change, the observed softening must have been due to a structural modification in the quenched and tempered alloy, *i.e.*, a coalescence of the carbide; this alteration was scarcely noticeable under the microscope.

Stresses in the Tyres of Locomotive Wheels. (Engineering, 1935, vol. 140, Oct. 25, pp. 439–440). After referring to previous experiments carried out by E. G. Coker and R. Levi on the problem of the stresses produced by shrink- and force-fits, an account of further researches by E. G. Coker and M. Salvadori is furnished. A model wheel and rail system was constructed, in which the rail was mounted on the periphery of a disc, so supported as to simulate the chairs of an actual track. The stresses in the wheel were analysed by photo-elastic methods. The graph of the stress distribution within the tyre was found to assume a wave-like form; the distribution varied, however, within the tyre itself. The investigation included an examination of the effects of loads applied at various points on the tyre where the influence of the balance weight and crank-web could be neglected. The contact pressure between the rail and tyre was found to be considerably affected; when to this the further disturbing factor of the chairs is added, and when account is also taken of the influence of tractive effort, the stress distribution in the tyre becomes exceedingly complex.

X-Ray Investigation of Stress Distribution and Overstresses in Mild Steel. H. Möller and J. Barbers. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1935, vol. 17, No. 12, pp. 157–166). The authors set out to determine whether the occurrence of overstresses were bound up with the existence of unequal stress distribution, and whether there were any relation between the stress gradients and the magnitude of the overstresses. A series of bend tests was made on specimens with variously steep stress gradients and of tensile tests on test-pieces in which the stress distribution was theoretically uniform. Only for comparatively small loads was a simple linear relation observed between the load and the stress. At higher stages of loading the stress distribution, even in the tensile test, was very non-uniform, even below the yield point as ordinarily understood. Even under theoretically uniform loading, stress differences between neighbouring groups of crystallites were set up, the magnitude of which in the bend test became equal to the intentionally produced stress gradients. As a consequence, even below the yield point plastic deformation took place in individual crystallite groups; as a result, the stresses in these crystallites decreased, whilst those in the neighbouring crystallites which were still behaving elastically increased. Hence, no clear relation between the theoretical stress gradients applied and the overstresses could be found. The X-ray measurement of the transverse elongation led to values of the ratio E/ν (E = elastic modulus, ν = Poisson's ratio) which in all cases were lower than those obtained by mechanical methods. By selecting certain crystal groups for X-ray measurement, having regard to their elastic anisotropy, an explanation for the observation was found.

Development and Present Status of the X-Ray Photographic Process in the Testing of Materials. A. Herr. (Messtechnik, 1935, vol. 11, pp. 129–131). A practical method is described for the X-ray examination of large specimens (bridge girders) by the operation of several X-ray tubes for the one exposure.

X-Ray Method for the Measurement of Elastic Stresses. R. Glocker. (Zeitschrift für Metallkunde, 1935, vol. 27, Sept., pp. 196–198). The author describes the mathematical principles of an X-ray method of determining individual elastic stresses, and the testing-out of the method by means of tubes subjected to internal pressure and steel bars under torsion.

Die Failures. Their Diagnosis and Cure. L. H. Williamson. (Metal Progress, 1935, vol. 28, July, pp. 32–37). Numerous die failures are quoted, and their causes and prevention are indicated. Many failures are shown to be due to improper heat treatment; others are the result of fatigue, or incorrect design, or of grinding and hardening cracks. Finally, a recommended procedure for the local hardening of dies is presented.

Contribution on the Examination for Internal Defects in Railway-Wheel Tyres. G. Dubois. (Mémoires de la Société des Ingénieurs

Civils de France, 1935, vol. 88, May–June, pp. 406–410). The prime causes of tyre failure are cavities due to piping and cracks. If correctly designed moulds are used the ingot pipe should occupy a position such that it is removed when the tyre blanks are punched out. Cracks are generally due to too early mould stripping, or too rapid or inadequate reheating for forging. The author thinks that the normal tests, however stringent they may be, are insufficient, because they are applied to only one tyre in a batch; the English method of dropping each tyre from a height seems to him to be of little value. He suggests that each tyre should be submitted to an elastic deformation test, by applying pressure to the inside at the opposite ends of a diameter and again at points on the diameter at right angles to the first, the pressure being adjusted so that the most severely stressed fibre would be supporting a stress a little below its elastic limit. A defective tyre would probably break in this test, or, at least, examination of its pressure curve would point to its defectiveness.

Fractures without Deformation of Boiler Parts. W. Ruttmann. (Zeitschrift des Vereines deutscher Ingenieure, 1935, vol. 79, Dec. 28, pp. 1561–1564). The fractures without deformation of boiler parts have been ascribed to a variety of causes. The author's purpose here is to examine whether the various types of damage present similar features, and whether it is possible to draw conclusions from laboratory tests in explanation of them. He first discusses intercrystalline fractures and fatigue fractures, and the constructional and operating conditions which may give rise to them (a statistical collation of the characteristics of the fractures at rivet holes, in plates and flanges, &c., is presented), and then discusses various forms of laboratory tests. In conclusion he asserts that fractures without deformation are not necessarily fatigue fractures; (corrosion-)fatigue stressing is probably all-important in the cracking of flanges, but in the case of rivet holes, for instance, this explanation does not suffice, for consideration of a large number of undeformed fractures in a variety of parts of boilers points to some other, as yet unknown, cause of a static nature.

The Correlation of Spring-Wire Bending and Torsion Fatigue Tests. E. E. Weibel. (Wire and Wire Products, 1935, vol. 10, Dec., pp. 560–577, 588). The investigation reported in this paper was an attempt to correlate bending and torsional fatigue tests for tempered Swedish valve-spring wire, so that the torsional fatigue strength might be inferred, within reasonable limits of accuracy, from the fatigue values derived from the rotating beam test. After reviewing the published literature on the subject, the author describes the methods of gripping the specimens which were devised; they involved the use of cast ends (of type metal). The fatigue values for zero-to-maximum (pulsating) torsional stress, using straight specimens in the as-received condition, were about 70% higher than values estimated from previous tests on carefully coiled springs.

The smaller of two sizes of wire tested in the as-received condition had the higher torsion fatigue limit and the lower ultimate torsional strength. Removal of the natural surface by grinding increased the bending fatigue strength by about 20%, but decreased the torsional fatigue strength by about 4%; shot-blasting improved the bending fatigue strength by about 27% and also increased the torsional fatigue strength. The zero-to-maximum torsional fatigue limits for the two sizes of wire used were between 1·5 and 1·6 times their respective bending fatigue limits; values of 0·84 and 0·90 were obtained for the ratio of reversed torsional fatigue strength to the reversed bending fatigue strength. Approximate measurements of surface residual stress were made on wire in different conditions before and after fatigue testing and before and after coiling; it is considered that these stresses may have a bearing on the fatigue properties of springs.

The Strength of Materials under Combined Alternating Stresses. H. J. Gough and H. V. Pollard. (Institution of Mechanical Engineers: Metallurgia, 1935, vol. 13, Nov., pp. 17–20). The authors describe a machine for testing specimens under combined alternating stresses of torsion and plane bending, and record some results obtained by its use. The present report deals with tests on three materials: A mild steel, a heat-treated nickel-chromium steel, and a silicon cast iron (Silal). The behaviour of the mild steel is seen to be in almost exact agreement with the von Mises-Hencky constant shear energy theory; but this cannot be regarded as a general criterion for steels, since the behaviour of nickel-chromium steel conformed to the constant total energy curve. Silal conformed fairly closely to the criterion of failure by constant principal stress.

The Cast Crankshaft. A. Thum and K. Bandow. (Zeitschrift des Vereines deutscher Ingenieure, 1936, vol. 80, Jan. 4, pp. 23–27). In recent times attempts have been made to use cast crankshafts as well as forged ones. The authors describe fatigue tests which show that cast crankshafts can be used, provided that they are suitably designed. In fatigue bending and torsion tests on crankshafts of steel, malleable iron, and Perlit iron, it was found that, for all designs, the bending fatigue strength was lower than the torsional fatigue strength. By suitable design it was found possible to raise the endurance of cast crankshafts considerably, so that they were no longer much inferior to forged crankshafts. Advantages of the cast type are the almost unlimited design possibilities, the reduced weight, and the low cost attainable by mass production. Other experiments were made with the purpose of bringing the strength due to shape (*Gestaltfestigkeit*) of cast crankshafts up to that of forged ones by suitable design.

Hardness Testing. R. A. Halloway. (Steel Treatment Society, Australia: Heat Treating and Forging, 1935, vol. 21, Aug., pp. 377–381; Sept., pp. 435–438, 451). A short introduction to the subject of hardness testing is followed by a classification of the types

of hardness testing machine, according to the method of indentation. The *modus operandi* of several hardness testing machines are described, including the numerous variants of the Brinell type of instrument, the Rockwell machine, the Shore scleroscope, the Herbert pendulum tester, and the Cloudburst test. The second part of this article covers certain theoretical considerations relative to hardness testing. These include a discussion of the methods of assessing the hardness number in the indentor type of machine and an analysis of the effects (deformation of the indentor, elastic recovery of the specimen, piling up of the deformed metal, and friction) which accompany the use of this machine. The relation between ball and pyramid hardness, and that between the hardness and other physical properties are among the other matters touched upon.

Influence of Uranium on the Structural Condition, Hardenability, and Retention of Hardness of Carbon Steels. H. Bennek and C. G. Holzscheiter. (Archiv für das Eisenhüttenwesen, 1935, vol. 9, Oct., pp. 193–200 : Technische Mitteilungen Krupp, 1935, vol. 3, Nov., pp. 196–204). Alloying tests showed that uranium-steel casts practically free from segregation could be made, with low metal losses, by adding low-carbon low-percentage ferro-uranium in small pieces to the well deoxidised steel in the ladle. High-carbon high-percentage ferro-uranium is unsuitable, as it dissolves with too much difficulty. In the range of steels examined, all the casts were completely forgeable with up to 5% of uranium. Addition of this element to carbon steel gives rise to two new structural components—probably carbides. Hardening and tempering tests showed that uranium is to a certain extent soluble in γ solid solution, but only limited use can be made of this, as fusion sets in even at relatively low temperatures. Uranium additions increased the degree of hardening for a given hardening temperature and reduced somewhat the susceptibility to overheating. The element acts as a carbide former, like chromium. The improvement of the mechanical properties of structural steels by additions of uranium is slight.

Development and Results of the Investigation of Age-Hardening. G. Wassermann. (Archiv für das Eisenhüttenwesen, 1935, vol. 9, Nov., pp. 241–245). The author discusses the discovery of the age-hardening of duralumin, the practical and scientific importance of age-hardening, the precipitation theory, tests to reveal precipitation, and the conditions preceding precipitation, and concludes by comparing the phenomena of age-hardening in aluminium alloys and in iron alloys.

Temper-Brittleness in Cast Iron and the Influence of Nickel and Molybdenum. J. E. Hurst. (Foundry Trade Journal, 1935, vol. 53, Nov. 14, pp. 372–373). During an investigation of the effect of alloy additions on the properties of aluminium-chromium and plain chromium cast irons suitable for nitriding, certain

changes in mechanical properties were observed, analogous to the temper-brittleness phenomena in steels. Previous experiments on plain nitriding cast iron containing 1·58% of chromium and 1·37% of aluminium had failed to reveal any temper-brittleness; however, when tests were carried out on similar cast irons to which nickel had been added a marked reduction in the strength properties after submitting the irons to a nitriding heat treatment was observed. Thus, chromium-aluminium-nickel cast irons containing 0·84% and 1·18% of nickel lost approximately 12% and 20% of the original strength after being heat-treated at 500° C. for 90 hr., and the tensile strength of an alloy of the same type, containing 1·95% of nickel, fell from 38·3 to 19·7 tons per sq. in. after being subjected to a nitriding heat treatment. In the light of these results further tests were carried out on nickel-chromium nitriding cast irons (free from aluminium, however) some specimens of which contained 0·25% of molybdenum. These specimens were given a nitriding heat treatment. Molybdenum was found to repress the temper-brittleness effect, except in the case of an iron containing 2·5% of nickel—although even in this example the presence of a larger amount of molybdenum would probably have given the desired protection. Further experiments on aluminium-chromium alloys containing nickel and molybdenum showed that the latter element is effective in inhibiting temper-brittleness in these cast irons.

Influence of Phosphorus on Temper-Brittleness. H. Bennek. (Technische Mitteilungen Krupp, 1935, vol. 3, Nov., pp. 205–213). *See* Journ. I. and S. I., 1935, No. II., p. 431.

Present Status of the Measurement of Surface Roughness. Schumacher. (Maschinen-Bau und Betrieb, 1935, vol. 14, pp. 379–383). The surfaces of two test-pieces can be observed simultaneously by means of the Busch comparative microscope. In the "touch" process, the movements of a needle passing over the surface of the material are recorded. In the Zeiss instrument the object is illuminated vertically and the profile curve is observed at an angle of about 45°. The optical processes have the disadvantage that smooth shining surfaces make the measurements difficult on account of the unavoidable reflection; on the other hand, the needle "touch" process is more sensitive. By the comparative microscope, rapid roughness determinations can be carried out.

Steels and Alloys for Permanent Magnets. A. Michel. (Seventh International Congress on Mining, Metallurgy, and Applied Geology, Paris, Oct. 20–26, 1935: Revue de Métallurgie, Mémoires, 1935, vol. 32, Oct., pp. 482–486). A review of the properties of alloy steels used for permanent magnets.

Present Status of Ferromagnetic Theory. R. M. Bozarth. (Electrical Engineering, 1935, vol. 54, Nov., pp. 1251–1261). In this article the present position of ferromagnetic theory is reviewed, from the point of view of elementary atomic physics. The author

discusses the structure of the atom, and especially the relation between the movements of the electrons within the atom and the magnetic behaviour of the materials; the theory of "domains," the effect of crystal structure, magnetostriction, and the effect of strain; and the precipitation-hardening associated with certain magnet steels. Finally a table of data concerning the origin of the forces responsible for various magnetic properties is presented.

Thermomagnetic Analysis of Siderurgical Products and its Recent Applications. P. Chevenard. (Métaux, 1935, vol. 10, Sept., pp. 194–208). The author describes in detail the thermomagnetometer used in the Imphy Laboratories, the principle on which it works, and its adjustment, use, and calibration, and then gives a number of examples of its use and of the indications which it gives.

On the Problem of Changes in Iron between 70° and 700° C. G. Naeser. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1935, vol. 17, No. 15, pp. 185–190). The author has determined the specific heat of pure iron between 70° and 700° C. and has plotted the values obtained in a curve. The graph shows clearly six well-defined reversible discontinuities, which occur at 112°, 198°, 292°, 388°, 487°, and 591° C. The temperature intervals and also the heat quantities evolved at the discontinuities in the curve appear to be simply related to one another.

The Measurement of the Specific Heat of Iron at High Temperatures. K. Meliss. (Archiv für das Eisenhüttenwesen, 1935, vol. 9, Oct., pp. 209–212). The specific heat of iron with 0·06% of carbon at various temperatures has been measured with a water calorimeter by the method of mixtures. The heat lost from the specimen in transit from the furnace to an intermediate container, provided in order to avoid losses from splashing and steam evolution, was determined. The magnitude of the experimental errors and their influence on the final result were checked. With all sources of error excluded so far as possible the scatter of the results of the absolute measurement of the specific heat amounted to $\pm$ 0·1%; the relative accuracy was determined as 0·05%. It is advocated that the specific heat should be measured relatively by reference to a standard material, for which sintered corundum is suggested.

The Thermal Conductivity of Pure Iron and Commercial Steels. F. Bollenrath and W. Bungardt. (Archiv für das Eisenhüttenwesen, 1935, vol. 9, Nov., pp. 253–262). On the basis of the literature of the last few years, the author presents a review on the thermal conductivity of practically pure iron, unalloyed and alloy steels. Only for plain steels at room temperature is it possible to formulate a reliable average value; the data for alloy steels are incomplete and contradictory, and give only a qualitative indication of the influence of alloy additions. Thermal conductivity values are given for a few types of steels used commercially.

The Influence of Cold-Working on the Thermal Conductivity. G. Tammann and W. Böhme. (Annalen der Physik, 1935, vol. 22, pp. 500–506). By a comparative method, the relationship of the thermal conductivities of a hard and a soft wire were measured and hence the relative diminution of the thermal and of the electrical conductivity due to cold-working was worked out. Both effects were very much alike, within the limits of experimental error, and likewise the " recovery " curves were very similar. The experiments were made on a number of metals, including iron. Other tests showed that rolling produced no anisotropy of the thermal conductivity, as was already known with regard to electrical conductivity.

Note on Steels and Cast Irons for Parts in Use at High Temperatures. L. Bovet. (Arts et Métiers, 1935, vol. 88, Dec., pp. 269–272). The influence of alloy additions on the properties of steels and cast irons at raised temperatures is discussed.

The Influence of a Low-Graphite, Low-Silicon Pig Iron on the Mechanical Properties of Grey Cast Iron at Raised Temperatures. M. Paschke and F. Bischof. (Giesserei, 1935, vol. 22, Dec. 20, pp. 625–627). Experimental melts containing different proportions of a special pig iron (white HK-Special pig of the Hochofenwerk Lübeck A.-G.: total carbon, 4·39%; graphite, 0·08%; silicon, 0·06%; manganese, 0·25%) were prepared, and their hot mechanical properties were determined. With increasing proportions of special pig, the tensile strength, Shore hardness, and notch toughness at raised temperatures all improved, although there was very little difference between the chemical compositions of the materials.

Standardisation of the Creep Test on Steel. H. Schmitz. (Stahl und Eisen, 1935, vol. 55, Dec. 19, pp. 1523–1534). The Sub-Committee on Tensile Testing of the Verein deutscher Eisenhüttenleute has been giving consideration to the drawing up of a provisional specification for the carrying out of the creep test on steel (*see* following abstract). In the present article the author discusses the following points: The need for a standard method of determining the creep strength of steel; the laying down of the specification; considerations on the suitable preliminary heating period, the duration and degree of prestressing of the specimen, and also the minimum testing time in the short-time test under constant temperature and load; the rate of extension on which the creep strength is to be calculated; consideration of the permanent extension; scattering of the results of two test series carried out on the proposed system; and comparison of the creep strength values obtained with the creep limit suggested by Siebel and Ulrich. Discussion in the Sub-Committee is also recorded.

According to the specification, time/total-extension curves shall be determined on specimens, preheated for 18–22 hr., during 45 hr. under constant load and temperature; the creep strength shall be taken as the greatest load under the effect of which the rate

of extension during the twenty-fifth to thirty-fifth hours does not exceed 0·001% per hr. Besides the vanishing of the rate of extension, which is thus determined, the initial extension is also to be considered; for individual steels this may vary considerably, though the rate of extension may be the same, and is not constant for different structural sections. In any case no value for the creep strength should be accepted for which the permanent extension exceeds 0·2% after 45 hr.

During the discussion careful consideration was given to the question whether Siebel and Ulrich's definition of the creep limit (that stress under which the rate of extension, after the attainment of a permanent extension of 0·2%, does not exceed 0·0001% per hr.) could be accepted. It was rejected, however, because it is more trouble to determine the creep limit than the creep strength from the time/total-extension curves; further, extrapolation is involved, and this is undesirable for acceptance tests. The creep limit offers no greater protection against excessively high permanent extension than does the creep strength, and therefore has no advantage as a basis of design calculation.

Provisional Specification of the Creep Strength of Steel. (Stahl und Eisen, 1935, vol. 55, Dec. 19, p. 1535). A brief statement of the proposals of the Sub-Committee on Tensile Testing of the Verein deutscher Eisenhüttenleute for standardising the creep testing of steel (*see* preceding abstract).

The Creep of Steels. L. L. Wyman. (Mechanical Engineering, 1935, vol. 57, Oct., pp. 625–627). Creep tests were conducted by the flow-rate method (in which the load is successively diminished to give a known rate of creep of, say, 1% per 100,000 hr.) on five nickel-chromium-molybdenum steels, the analyses of which were in the following range: Carbon 0·31–0·37, nickel 1·77–2·74, chromium 0·61–0·85, molybdenum 0·25–0·46, manganese 0·54–0·60, silicon up to 0·18%. The steels were subjected to various heat treatments before being tested. Considerable variations in the creep strength were obtained. These variations cannot be attributed to the heat treatment, since the effect of this differed in the various steels. Examination of the microstructures of these steels revealed that: (1) The variations in grain-size were as inconsistent as the creep results; (2) the degree of banding, or dendritic segregation, in these steels was in direct ratio to their creep properties in the annealed state; (3) heat treatment did not influence the creep strength of unbanded material, but it did affect the strength of banded steel; (4) with severe banding heat treatment was usually advantageous. It follows that banding should be eliminated if possible, and that if present its effect may be minimised by suitable heat treatment. The latter is applicable to steels operating at temperatures up to 450° C., since the effect of heat treatment persists within this temperature limit. At temperatures in excess of 550° C., however, gradual annealing takes place. It has

been shown by experiments that a structure free from banding, and having a high creep strength, may be secured if an adequate reduction in the forging operation is adopted; a reduction of at least ten to one is desirable. The problem may be attacked in another way, by controlling the formation of dendrites during the cooling of the ingot. If the ingot mould is heated to 100° C., for instance, crystallisation begins at a small number of nuclei, and dendritic segregation results. If the mould is heated to 550° C., however, crystallisation from many nuclei takes place, dendritic growth and subsequent banding are inhibited, and a satisfactory grain structure is produced. Refinement may also be brought about by only partly killing the steel; the agitation of the freezing metal consequent on the evolution of gases appears to promote a finer primary grain structure.

The Utilisation of Creep-Test Data on Engineering Design. R. W. Bailey. (Institution of Mechanical Engineers, Nov. 22, 1935: Engineering, 1935, vol. 140, Nov. 29, pp. 595–596; Dec. 13, pp. 647–651). This paper is divided into two parts. Part I. deals with creep data and their utilisation in design problems. It is pointed out that the tensile creep test is the most important, and two cases are considered, (*a*) in which the stress is constant, or substantially so, and (*b*) in which the stress diminishes with time. The author suggests that creep test data should be based on a total permissible deformation which would rarely exceed 0·005 in. per in. and in most cases be less. By way of example (a forged 0·5% molybdenum steel) he outlines the procedure adopted in determining the creep characteristics of a steel required for high-temperature service. The results of tests at various stresses and temperatures are plotted to give the relation between stress and temperature for a total creep of 0·001 and a period of 100,000 hr. Further tests, on specimens initially heated to a temperature in excess of the temperature of creep-test, disclosed that this treatment brought about a considerable change in the creep behaviour; in general, a stiffening followed by a weakening of the material was produced. The author goes on to discuss creep tests under diminishing stress and their relation to constant-stress tests, and in this connection shortly considers the case of material for bolts and studs working at high temperatures under diminishing stress. The design of parts under simple and compound stress is next analysed. Space is then devoted to an examination of problems in which creep is important; these include steam piping and tubes, rotating discs, and multiple-disc rotors. In Part II. details of an experimental investigation of the general shear stress system are furnished. The work was carried out on thin-walled mild steel tubes under tension and torsion, and lead pipes under internal fluid pressure and externally applied axial loading. It was found that the creep rate for simple tension can, under suitable temperature and stress conditions, be appreciably greater than twice the corresponding

rate for simple shear. The author discusses this result, and derives the general form of the expression for creep under compound stress; on the basis of this expression he analyses the results obtained from experiments on thin-walled steel tubes.

The Creep Strength of Welded Boiler Plates in the Unannealed and the Annealed Condition. C. Appaly and F. Sauerwald. (Metallwirtschaft, 1935, vol. 14, Oct. 25, pp. 858–861). Investigations have shown that the creep strength of a welded boiler-plate joint is higher than that of the parent plate and of the melted-down weld material; this arises from the fact that internal stresses and structural forms occur which hinder the deformation. This can be shown by annealing welded joints; removal of the internal stresses, and development of the structure to resemble that of the parent plate, each remove about half the restraint on the deformation, so that by both effects together the creep strength of the annealed joint becomes about the same as, or slightly less than, that of the plate material. For the constructor who will use the welds, these determinations are of importance, in that in every condition the joints (given good workmanship) do not constitute a dangerous spot in the construction, even after prolonged static loading in the region of 400° C. Comparison of the results of the short-time test, in which the creep strength is determined from the break in the elongation-rate/load curve, with those derived from long-time tests shows the former to be satisfactory.

Report of Creep Tests for Gas Welded Steel. N. F. Ward. (Journal of the American Welding Society, 1935, vol. 14, Oct., pp. 13–19). The tests described were undertaken to determine the performance of cold-drawn steel (0·09% carbon content) and gas-welded steel of the same type under elevated temperatures and various stresses. Two specimens were used for each test, one welded and the other unwelded. Short-time and long-time tests were conducted on test-pieces in the as-drawn (or as-welded) and annealed conditions, and between a temperature range of 350–998° F. and a tensile stress range of 5600–12,700 lb. per sq. in. Specimens in the annealed state yielded lower creep limits than those not so treated. Although within the range 200–400° F. the creep resistance of both the cold-drawn and welded material is good, at higher temperatures it is less satisfactory, and for this reason 0·09% carbon steel is not recommended for high service temperatures.

Iron of High Purity. F. Adcock and C. A. Bristow. (Proceedings of the Royal Society, 1935, vol. 153, pp. 172–200). The authors describe the preparation and the mechanical and physical properties of a number of iron samples of high purity, which were prepared and investigated at the National Physical Laboratory during a period of about eleven years. During this time various improvements in the method of preparation were introduced and the final batch was obtained directly from ferrous chloride to avoid contamination with nickel. The previous four batches were prepared from electrolytic

iron. The density, coefficient of expansion, electrical resistivity, thermal conductivity, transformations, magnetic properties, hardness, malleability, and tensile properties were investigated. A comparison of the results for different batches of iron shows that measurable differences existed in some of the physical properties. Thus, the higher purity batch 5 iron possessed a slightly higher electrical resistivity than two of the earlier batches. This does not confirm the usually accepted view that the lowest electrical resistance is associated with an element in the purest form. Again, the observations of the magnetic permeability for low and moderate values of magnetising force do not indicate that the purest iron possesses the highest magnetic permeability. Jones (Journ. I. and S. I., 1934, No. II., p. 429) in commenting on Yensen's hypothesis suggested that deoxidation of iron would suppress gamma iron. The present work does not support this view, however, since it was found that the alpha-gamma transformation was neither suppressed nor raised to any great extent in batch 5 iron, which contains very little oxygen or other impurities.

It is significant that the alpha-gamma transformation in the later batches of iron, as indicated by the dilatometric observations, does not take place at a constant temperature, but occupies a definite temperature range. If this temperature interval is attributed to the action of known foreign elements, then the minute traces of impurities found in batch 5 iron must be credited with an extraordinarily powerful influence—an assumption which should only be admitted when other explanations have failed. Comprehensive analyses have been conducted on this material, and the effect can hardly be attributed to some unidentified impurity. It would appear that the alpha-gamma transformation in high purity iron is not a simple phase change occurring at a constant temperature but is a more complex transformation. Further work is desirable, since a full understanding of this change is probably of great importance in connection with commercial iron alloys.

Physical Tests for Cast Iron. J. Shaw. (Foundry Trade Journal, 1935, vol. 53, Nov. 21, pp. 387–388). In view of the imminent revision of B.S. Specification 321/28 for grey cast iron the author examines certain factors which, he considers, should be taken into account. In the first place, he points out that a high-test cast iron usually depends for its tensile strength on a close-grained structure, but the same structure is not very favourable to impact resistance. Doubt also surrounds the use of test-bars. Although these are expected to show approximately the same strength as a specimen cut from the casting, the author remarks that the standard bars fall short of this requirement; he suggests that in no case should the test-bar as cast be of smaller cross-section than the average cross-section of the casting it represents. In addition to this, the metal usually varies from the edge to the centre, so that the practice of turning down test-bars is likely to give

misleading results. The results of recent experiments on test-bars of various sizes and cast from different mixtures have tended to confirm the author's contentions. Finally, attention is drawn to the fact that low-carbon border-line irons are often weak under impact.

New Information on the Use of Cast Iron as a Material of Construction. A. Thum. (Giesserei, 1935, vol. 22, Oct. 25, pp. 529–533). If the material be judged from the point of view of resistance to deformation, cast iron has many advantages on account of its low notch sensitiveness and the ease with which it may be shaped. Among other things, its advantages for light constructional work are pointed out and the problem of cast crankshafts is discussed.

Contribution on the Hot Strength of Cast Iron with Particular Reference to Thin-Walled Castings. W. H. Uhlitzsch and W. Leineweber. (Archiv für das Eisenhüttenwesen, 1935, vol. 9, Oct., pp. 185–192). As the literature gives various divergent explanations for the strength properties of cast iron at raised temperatures, the authors have made further tests in order to clear up the matter. Altogether, nineteen irons of various compositions (some plain, some alloyed with nickel, chromium, molybdenum, or silicon) were examined, and were submitted to mechanical and physical tests. The results suggest that the course of the hot-strength curves up to about 300° is conditioned by the magnetic transformation of the cementite; the possibility that other factors may have an accentuating effect is not excluded. Hot tensile tests on the alloy irons showed that the alloying elements tended to smooth out the curves; in the case of silicon and nickel this was attributable to a weakening of the intensity of the cementite transformation, and with chromium and molybdenum it was due to the transformation being shifted to lower temperatures. By means of test-pieces machined out of normal test bars, no difference in the behaviour of the corresponding castings of similar chemical composition could be detected in the laboratory, because, in addition to the internal stresses characteristic of each material, there were also casting stresses in the castings. It was demonstrated, however, that not only the origin of the pig iron and the melting process but also the moulding technique and casting practice employed have a determining influence on the behaviour of castings.

Production and Application of Alloy Cast Iron. E. Piwowarsky. (Zeitschrift des Vereines deutscher Ingenieure, 1935, vol. 79, Nov. 16, pp. 1393–1396). In the United States of America the use of low-alloy cast irons for less important purposes has decreased in the same way as it has done in other countries in recent years; on the other hand, the use of high-alloy irons for special purposes has increased. The author reviews the manufacture and applications of these latter irons in the U.S.A.; representative analyses of irons for specific purposes are given, and their properties are discussed.

Ni-Hard. (Foundry Trade Journal, 1935, vol. 53, Nov. 28, pp. 395–397). Ni-Hard is an alloy white cast iron in which nickel and chromium are the chief alloying elements. The nickel (added to the extent of about 4·5%) hardens the matrix and renders it martensitic, and also refines the grain. Unfortunately it also tends to graphitise the iron and turn a white iron grey; this is counteracted by the addition of chromium (up to 1·5%). The quality of the white iron also depends on the other elements present. The amount of carbon added influences the hardness and toughness; for maximum hardness a carbon content above 3·6% is used, for strength and shock resistance a carbon content below 3% is preferable. Since chromium, whilst retaining the carbides in solution, tends to reduce the strength of the iron, it is kept to a minimum; if the silicon is also reduced this can safely be done without decreasing the chilling effect. Manganese has a chilling effect which, however, is modified by the sulphur present; although the latter is also a chilling agent it tends to neutralise the action of the manganese. Molybdenum may be added to refine the grain. The following analysis is typical; it is suitable for light-section castings of maximum strength: Total carbon 3·0, silicon 0·8, manganese 1·2, sulphur 0·1, phosphorus 0·3, nickel 4·5, chromium 1·0%. For maximum hardness the carbon is increased; the hardness of the chilled face varies between 500 and 700 Brinell, according to the carbon content. Compared with ordinary chilled iron, not only is the hardness improved by the addition of nickel and chromium, but also the tensile strengths of the core and the chilled section. Wear tests show that Ni-Hard has a life from five to twelve times as long as that of plain chilled iron. Machining is difficult with Ni-Hard unless the alloying elements, and therefore the hardness, are reduced. Ni-Hard may be substituted for almost all applications in which chilled or white iron castings are normally employed, such as chilled rolls, the wearing parts of crushing and grinding machinery, pumps, pulverisers, and so forth.

Certainty of Results as the Basis for the Manufacture of High Test Gray Iron. E. Piwowarsky. (Transactions of the American Foundrymen's Association, 1935, vol. 42, pp. 705–736). The author contends that the improvement in the quality of cast iron brought about in recent years largely follows from the greater certainty of results now possible. After reviewing his earlier investigations, the author presents the results of new experiments upon the influence of silicon, phosphorus, nickel, chromium, molybdenum, tungsten, and copper, using hollow box-shaped castings for test-pieces. Silicon and phosphorus were found to have an unfavourable effect, but nickel, chromium, and molybdenum improved the quality of the iron. Tungsten and copper had either a neutral or slightly favourable effect. A new shear test is described; this test was used for determining the effect of the various alloying constituents. The author then develops a simple relation between the different

properties of grey cast iron; finally, the results of tests on singly-cast test bars are compared with those yielded by box-shaped test castings.

Some Experiments with Austenitic Cast Irons. P. A. Russell. (Foundry Trade Journal, 1935, vol. 53, Oct. 31, pp. 325–327). An investigation was carried out on the effect of variation in composition on the properties of Ni-Resist alloy cast iron, and more particularly of the effect on the solidification shrinkage. The standard composition of Ni-Resist is approximately as follows: Total carbon 3, silicon 1·5, manganese 1, nickel 12–15, copper 5–7, and chromium 2%. The results obtained from test bars made by the author from experimental melts are compared with tests on commercially produced Ni-Resist and with tests conducted by the International Nickel Company on the same type of alloy. Phosphorus, although conferring soundness in some cases, appears to have a bad effect on the strength and ductility. In view of this the author suggests that the following composition is suitable if ductility is not important: Total carbon 2·5–2·8; silicon 1·8–2·2; sulphur 0·08 max.; phosphorus 0·30 max.; manganese 1–1·5; nickel 13–16; copper 5–7; and chromium 1·5–2·5%. If ductility is important the standard Ni-Resist with about 3% of carbon should be used.

Modern Steels. A. C. Harris. (Manchester Association of Engineers: Iron and Coal Trades Review, 1935, vol. 131, Nov. 29, pp. 905–906). Among the matters dealt with by the author are steels for conductor rails and telegraph wire, rimming and solid steels, their salient characteristics and main applications, medium-carbon steels, and high-carbon steels. Some space is also devoted to a description of the special steels used for aircraft, automobile, and general engineering work.

The Era of Stainless Steel. L. M. Angus-Butterworth. (Sheet Metal Industries, 1935, vol. 9, Nov., pp. 699–700). The author briefly surveys the range of stainless steels, and their application in aircraft, building, motor-car, and marine work.

Special Steels for Heat Exchangers. Piveteau and Colvez. (Chaleur et Industrie, 1935, vol. 16, Aug., pp. 381–386). The authors first indicate the various types of corrosive attack at high temperature to which the metal in heat exchangers is subjected, and then review the properties—mechanical, physical, structural, &c.—of heat-resisting steels.

Heat-Resisting Alloys. (Heat Treating and Forging, 1935, vol. 21, Oct., pp. 485–487, 489). The physical properties and commercial applications of a new iron-chromium-aluminium alloy known as Smith Alloy No. 10 are described. (*See* Journ. I. and S. I., 1935, No. II., p. 518).

Alloys Good at Temperatures Above 2100° F. G. Nordstroem. (Metal Progress, 1935, vol. 28, Oct., pp. 68–69). The characteristics of the chromium-aluminium-cobalt-iron resistor alloys of the Kanthal type are compared with the well-known 80/20 nickel-

chromium resistor alloy. A typical alloy of the Kanthal type contains about 25% of chromium, 5% of aluminium, and 3% of cobalt, the balance being iron. These alloys have a higher specific resistance than nickel-chromium alloys, but the strength falls off sharply at high temperatures, rendering supports for the elements necessary. The elements will take a high surface load, and are stated to be particularly suitable for furnaces operating at temperatures in excess of 2000° F.

Manganese and Copper Additions to "18 and 8"—Armstrong Metal. L. C. Grimshaw. (Metals and Alloys, 1935, vol. 6, Oct., pp. 264–266). In an effort to produce an 18/8 alloy which would not require final heat treatment an alloy containing manganese and copper additions, and known as "Armstrong metal," has been developed. The alloy has the following typical composition: Carbon 0·10, manganese 4–6, chromium 17·5, nickel 8·0, and copper 2·9%; the ratio of manganese to copper should be 3 : 2 or 2 : 1. The metal forges easily, and may be readily rolled or cold-drawn; it is non-magnetic in these conditions. The Brinell hardness in the as-forged state is between 150 and 170; after heating to 1950° F. and subsequent cooling it softens, and the hardness falls to about 140. It is not difficult to machine, but, unlike the usual 18/8 alloy, it cannot be work-hardened. In the forged condition the ultimate strength is about 90,000 lb. per sq. in. and the elongation 42%; after oil-quenching from 1950° F. these figures become 80,000 lb. per sq. in. and 52%, respectively. The corrosion resistance of Armstrong metal is very good, especially in the presence of sulphuric acid, and although the structure of the alloy reveals considerable carbide precipitation at the grain boundaries the resistance to intergranular corrosion is high. Whilst the alloy is not intended to replace the usual 18/8 alloy, it may be usefully employed where heat treatment of the cold-worked, welded, or clad product is impracticable.

Alloy Steels for Boiler Drums and Superheaters.—Part II. G. K. Herzog. (Blast Furnace and Steel Plant, 1935, vol. 23, Sept., pp. 630–632). In concluding his discussion of alloy steels for use in high-temperature steam equipment the author examines the properties of molybdenum and other steels. These include a chromium-molybdenum steel containing 0·15% of carbon, 1–1·5% of chromium, and 0·5% of molybdenum; a molybdenum steel of similar composition, but lacking the chromium; a manganese-molybdenum steel containing 1·25% of manganese and 0·25% of molybdenum; a chromium-aluminium steel (analysis not stated); and a chromium-manganese-silicon steel of the following composition: Chromium 0·4–0·6%, manganese 1–1·4%, silicon 0·6–0·9%. Alloy steels for other power plant purposes also receive brief attention. (*See* Journ. I. and S. I., 1935, No. II., p. 500.)

Contribution on the Problem of Foreign Raw Materials for Special Steels for the Construction of Chemical Plant. P. Schafmeister.

(Technische Mitteilungen-Krupp, 1935, vol. 3, Nov., pp. 218–223). The author describes efforts that have been, and are being, made in Germany, to reduce the use of high-alloy steels, the alloying elements of which have to be imported under a heavy import tax. Thus, in many cases a low-carbon 17% chromium steel can be used in place of 18/8 chromium-nickel steel, or the latter can be made by the incorporation of nickel-steel scrap. Again, in the oil cracking industry a low-chromium molybdenum steel can be substituted for steel of the *V2A* type. Other examples are given. On the constructional side, recourse has been had to "clad" steel; the mechanical strength is provided by plain steel, while the acid-resistance, for instance, is given by a thin layer of special steel welded on where required; numerous examples of this procedure are also given.

The Further Development of Steels Resistant to the Weather Conditions. K. Daeves. (Mitteilungen der Kohle- und Eisenforschung G.m.b.H., 1935, vol. 1, Feb., pp. 1–8). *See* Journ. I. and S. I., 1935, No. II., p. 517.

Stainless Alloy Lining Lengthens Life of Oil Cracking Units. O. E. Andrus. (Iron Age, 1935, vol. 136, Nov. 21, pp. 32–33, 96, 98). Vessels for oil-cracking service are often subjected to severe pressure, temperature, and corrosion when in operation. Although carbon steels and low-alloy steels are capable of withstanding the pressure and temperature, the corrosive conditions require the adoption of special precautions. One method is to build the vessel with thick walls so that it will not be unduly weakened by corrosion; other methods include the processing of the oil to remove deleterious impurities, the use of ganister linings and refractory paints, and the application of chromium plating or sprayed aluminium. Cost prohibits the use of stainless nickel-chromium and chromium alloys for withstanding both the pressure and the corrosive conditions, but the author describes a method of fabrication in which the low cost of a carbon steel shell is coupled with the high corrosion resistance of the stainless alloys. A carbon steel shell is used for load carrying purposes, and to it an inner lining of stainless steel sheet is applied, spot-welded to the shell at frequent intervals.

High-Manganese Steel. L. Sanderson. (Metallurgia, 1935, vol. 12, Oct., pp. 171–172, 176). An account of the properties and uses of "Hadfield" manganese steel containing 12–14% of manganese is presented.

B.S. 3.S.11 Steel in Aircraft Structures. P. L. Teed. (Metal Treatment, 1935, vol. 1, Autumn No., pp. 135–140). B.S. 3.S.11 steel is one of the most extensively used materials in aircraft structures. A study has been made of the following properties of this steel: (1) The longitudinal mechanical properties of bars of different sizes in the as-received condition; (2) the influence of tempering temperature on these properties; (3) the difference between the longitudinal and transverse properties; (4) the influence of forging;

and (5) the effect of repeated hardening. B.S. 3.S.11 steel has the following range of composition: Carbon 0·25–0·35; silicon 0·30 (max.); manganese 0·45–0·70; sulphur 0·050 (max.); phosphorus 0·050 (max.); nickel 3–3·75; chromium 0·50–1·00%, molybdenum optional. In order to investigate conditions (1) and (2) above, specimens of $\frac{9}{16}$-in. bar were tested in the as-received and quenched and tempered states; the longitudinal and transverse properties were ascertained by cutting specimens from a 6-in. dia. bar; parts of this bar were forged down to enable the influence of forging to be estimated, and specimens of the $\frac{9}{16}$-in. rod were repeatedly quenched to investigate condition (6). The following conclusions are drawn: (1) Bars of B.S. 3.S.11 steel in the as-received state, while satisfying the specification requirements, show marked variations of the 0·1% proof stress; in view of the importance of the latter the proof stress should constitute a specification requirement; (2) material with a low proof stress may be made to satisfy the specification if a tempering temperature higher than that specified is used; (3) the decrease in the longitudinal mechanical properties of the steel from the circumference to the centre of a 6-in. dia. bar is not of a serious nature; (4) the transverse and longitudinal mechanical properties of a 6-in. dia. bar differ in that the transverse impact value is very low in comparison with the longitudinal one, and the ductility also is much lower; (5) the proof and ultimate stresses for transverse specimens do not seriously differ from those for longitudinal test-pieces; (6) forging raises both the transverse and longitudinal proof and ultimate stresses, reduces the transverse ductility, improves the longitudinal Izod value considerably and depreciates the transverse impact value; (7) repeated hardening and tempering has no adverse influence on the mechanical properties or microstructure of the steel; hence the existing prohibition should be abolished; (8) water quenching (not permitted in the specification) is likely to induce cracking.

Stainless Steels and Vitreous Enamelled Irons in Architecture. M. J. R. Morris and K. Kautz. (Industrial and Engineering Chemistry, 1935, vol. 27, Oct., pp. 1135–1137). A brief reference to the early use of metal in architecture is followed by the enumeration of the advantages of the use of steel as a surfacing material.

These advantages include faster and easier erection than when traditional building materials are used; thinner walls, which may be effectively heat and sound insulated; freedom from fire and weather hazards, and, compared with wood, greater certainty of supply—especially in view of declining timber resources. The salient features of stainless steel and vitreous enamelled iron are briefly examined and some examples of their application to building exteriors are cited.

Nickel Steels in Colliery Engineering. (Colliery Engineering, 1935, vol. 12, Oct., pp. 323–328). The greater demands now being made on the appliances used in colliery engineering, and on the

materials employed in their construction, renders the adoption of alloy steels advisable, if not imperative. Nickel steels suitable for this purpose are referred to; the range of steels explored includes plain nickel steels, nickel-chromium steels, and steels containing copper or molybdenum in addition to nickel. These steels have been applied to coal-cutters, conveyors, coal-washing plant, pump impellers, and mine cages (for saving weight); examples of these applications are cited.

Use of Special Steels in the Construction of Mining Plant. L. Lahoussay. (Seventh International Congress on Mining, Metallurgy, and Applied Geology, Paris, 1935: Revue de l'Industrie Minérale, Mémoires, 1935, No. 360, Dec. 15, pp. 636–643: Iron and Coal Trades Review, 1935, vol. 131, Dec. 6, p. 941). The use of special steels for the construction of various items of mining plant, such as the cages, their suspension, tubs, &c., and the advantages so gained are discussed.

Some Phenomena Concerning the Safety of Forgings. G. Delbart. (Revue de l'Industrie Minérale, Mémoires, 1935, No. 357, Nov. 1, pp. 507–522). After touching on the iron-carbon diagram, the author discusses various factors—such as the chemical composition and segregation, the structure, ageing, the regeneration of brittle steels by heat treatment, and fatigue (in regard to which he outlines the theory of secondary stresses and the theory of the hysteresis of pseudo-elastic deformations)—and their influence on the safety of forgings.

Selection of Die Steels for Plastic Moulding. (Steel, 1935, vol. 97, Nov. 18, pp. 30–33). The principal qualities required in dies for plastic moulding include resistance to wear and corrosion, workability, and toughness in the core. The author explains that there are four materials in common use for these dies; they are machine steel (case-hardening mild steel), tool steel, low-carbon alloy steel and nitralloy. The advantages and disadvantages of each are examined. Sometimes chromium plating is used to protect the surfaces of the dies, because of its high abrasion and corrosion resistance. A new steel known as Bakadie has been developed for bakelite moulding; it is a nickel-molybdenum steel of low carbon content, yielding a Rockwell hardness of 63–65 on the surface after case-hardening and appropriate heat treatment, and a tough core. In conclusion, the author describes in detail the carburising procedure and heat treatment used on a die, weighing 7 tons, for producing plastic mouldings weighing 9 lb.

"Isteg" Steel Bars for Concrete Reinforcement. (Engineering, 1935, vol. 140, Nov. 8, pp. 508–509). **Isteg Steel.** (Engineer, 1935, vol. 160, Nov. 15, p. 521). Brief particulars of Isteg steel rod for the reinforcement of concrete are furnished. The reinforcing rod is made by twisting two bars of mild steel to form a two-stranded rod. During the twisting operation the heads do not approach each other, with the result that the bars are stretched

beyond the elastic limit and thus given a higher elastic limit stress. Tests in which reinforcing rods embedded in concrete were pulled to fracture showed that the reinforcement broke at a stress of 70,000 lb. per sq. in., the bond strength between the concrete and reinforcement being 580 lb. per sq. in. Cantilever tests on plain hooked bars and Isteg bars (without hooks) indicated that the performance of the latter is greatly superior to that of the former.

Third International Congress on Rails, Budapest. (Montanistische Rundschau, 1935, vol. 27, Oct. 16, Stahlbau-Technik, pp. 4–8). Brief abstracts are given of the following papers, which were presented at the Third International Congress on Rails, held in Budapest, on Sept. 8–12, 1935 :—

M. Ros and A. Eichinger : Laboratory tests and experience of plain, composite, and heat-treated rails.
R. Kühnel : Attempts to improve rail material in Germany.
F. Körber and J. Mehovar : Contribution to the knowledge of the changes with time of the mechanical properties of newly-rolled rails, particularly of basic Bessemer steel.
W. Titze : The appraisal of basic open-hearth steel rails on the basis of technological and static tests on them and the metallurgical condition of the material.
E. H. Schulz : Self-stresses and fatigue strength of rails.
J. Bartel : The problem of the notch-toughness of rail material.
R. Walzel : The problem of switch rails and crossings.

The First German Railway Rail. H. Dickmann. (Stahl und Eisen, 1935, vol. 55, Dec. 12, pp. 1509–1512). The first railway rail produced in Germany was rolled in 1835 by the firm of Heinrich Wilhelm Remy and Partners, of Rasselstein, for the Ludwig Railway Company. The material used was " first-quality superior " iron; the rails weighed 4·2 kg. per ft., so that the 15-ft. lengths which had to be supplied weighed 63 kg. each. This article gives an account of the difficulties encountered by the railway in their endeavour to obtain rails made in Germany.

The Effect of High Wheel Pressure on the Surface of Wheel and Rail. H. Egen. (Technische Mitteilungen Krupp, 1935, vol. 3, Nov., p. 227). A railway wagon wheel was pressed, under various loads rising to 70 tons, on the surface of standard rails; two pieces of carbon copying paper placed in between made marks on the surfaces where they were pressed into contact. The measurements of these imprints for the various loads and two sections of railhead are recorded. No indentation was observed on either the wheel rim or the rails even after the heaviest loading.

Internal Fissures in Railroad Rails. H. F. Moore. (Metal Progress, 1935, vol. 28, Nov., pp. 46–52). This article is based on Bulletin No. 376 of the American Railway Engineering Association. It is known that internal fissures sometimes develop in rails, leading to failure. Examination of the stresses imposed on the rail during

service shows that the shear stresses approach the ultimate shear strength of the rail. However, certain rails suffer from shatter cracks, and it has been found by experiment that the development of internal fissures is closely related to the occurrence of shatter cracks. If fissuring is to be avoided shatter cracks must be eliminated; so far no suitable device for detecting shatter cracks in rails appears to have been produced, but experiments on varying thermal treatment indicate that work in this direction may yield better results.

Is it Possible to Determine the Quality of a Steel Wire Rope by Mechanical Tests? P. R. Clark. (Moniteur du Petrole Roumain, 1936, vol. 37, Jan. 1, pp. 33–43). The author first discusses the characteristics desired in wire ropes (such as metallographic homogeneity, uniformity of diameter of the wires and core, regularity of the mechanical properties), certain factors in the making of the ropes, the superiority of acid over basic steel for this purpose, and the flexibility of wire ropes. He then deals with the mechanical properties required in wire ropes, methods of testing them, and the response which the ropes or the wires should make to them. The author concludes that mechanical tests are inadequate to determine the homogeneity of wire ropes and the component wires—a question of prime importance—though fatigue tests may raise the mechanical testing to a higher level.

Tests of Steel Tower Columns for the George Washington Bridge. A. H. Stang and H. L. Whittemore. (Journal of Research of the National Bureau of Standards, 1935, vol. 15, Sept., pp. 317–339). Columns for the George Washington suspension bridge across the Hudson River at New York City were tested in the hydraulic compression machine at the Bureau. The columns were made of carbon steel, silicon steel, and carbon-manganese steel; measurements of the shortening and lateral deflection were made, and tensile tests on specimens of the material were also conducted. The carbon-steel columns exhibited the phenomenon of pick-up (*i.e.*, an initial definite maximum load, a constant or slightly decreasing load for a further shortening of the column, followed by a pick-up to a second higher maximum load after the column was markedly deformed). The silicon steel columns showed no definite initial maximum load, the load increasing slowly, then rapidly, as the column shortened. The carbon-manganese steels gave no indication of more than one maximum load. The column yield strengths for the silicon-steel and carbon-manganese-steel columns were respectively 1·55 and 1·71 times that for the carbon-steel columns; these ratios are practically the same as the ratios of the yield strengths of the materials. Failure was by local buckling; it only occurred after considerable shortening of the column and was not the primary cause of failure. In general, the tests confirmed the conclusion that tensile yield tests furnish a close measure of the strength of short sturdy columns.

METALLOGRAPHY AND CONSTITUTION

Mode of Action of Carbide Etching Reagents. R. Mitsche. (Archiv für das Eisenhüttenwesen, 1935, vol. 9, Dec., pp. 311–312). Tests made on various alloy steels showed that for an etching reagent to be of use for carbide etching, an oxidising medium and hydroxyl ions together are necessary. A solution of potassium permanganate in caustic potash or soda was found to be particularly serviceable. The action of the carbide etching reagents is probably the following: Under the influence of the caustic solution ferro-ions go into solution from the less noble ferrite and the resulting hydrogen ions are discharged on the more noble cementite. The hydrogen is then oxidised to water by the oxidising medium and the ferrous hydroxide forming from the ferro-ions is oxidised to ferric hydroxide; the latter precipitates on the cementite, giving it a dark colour, the intensity of which depends on the duration of etching.

Determination of the Purity of Steel by Deep-Etching. E. Houdremont and H. Schrader. (Archiv für das Eisenhüttenwesen, 1935, vol. 9, Dec., pp. 273–275). Experiments on the deep-etching test on longitudinal and transverse sections of unalloyed electric and open-hearth steels showed that for the determination of the impurity of steel, whether due to inclusions or to phosphorus segregates, by deep-etching, it was essential to carry out the test on heat-treated material; in the untreated condition prior attack occurred at the grain boundaries, particularly of coarse grains, and this led to confusion. After suitable preparation deep-etching on longitudinal sections revealed principally phosphorus segregates, and on transverse sections primarily sulphide inclusions. For this reason the deep-etched transverse section is more suitable for the differentiation of steels of various metallurgical origins. The formation of individual pits instead of a uniform fibrous etched surface was due to the dissolving out of individual inclusions in the first case and of innumerable inclusions lying close together in the second; for this reason conclusions regarding the uniformity of material should not be drawn from such an individual local attack. The applicability of the deep-etching test for judging the quality of steel is limited.

Dry Polishing Specimens for Microscopic Examination. K. H. Priestley. (Foundry, 1935, vol. 63, Oct., pp. 30–33, 72). A method of preparing specimens for microscopic examination is described in which the final polishing (after the surface has been rendered smooth by successive grades of emery) is performed with damp rouge on a velvet disc, until the previous grinding marks have been

removed; the specimen should not be overpolished. Specimens of cast iron prepared in this way preserve the graphite flakes intact, whereas the usual wet polishing removes them and produces enlarged cavities. After discussing the polishing technique the author suggests that the following points should be observed: (1) The minimum amount of water should be used; (2) the disc should run at 400–600 r.p.m.; (3) light pressure only should be applied; (4) a good grade of rouge should be employed; (5) the cloth should be medium nap velvet; (6) the specimen should be rotated to prevent cometing; (7) the wheel should be well charged with abrasive. The dry polishing method may be applied to steels, malleable irons and non-ferrous alloys, as well as to grey and white cast irons. The article is illustrated by numerous micrographs depicting the results obtainable.

X-Ray Equipment for Studying Metal at High Temperatures. N. P. Goss. (Metal Progress, 1935, vol. 28, Oct., pp. 163–166, 176). Apparatus for the determination of X-ray diffraction patterns at high temperatures is described. It consists of a metal X-ray tube with a water-cooled target, evacuated by mercury pumps, and operating at 35,000 V. and 50 m.amp. A refrigerating unit placed between the X-ray tube and the gas pumps prevents diffusion of the mercury vapour into the tube. The diffraction cassette is a bakelite cylinder around which the film is wrapped, and down the centre of which the specimen (in the form of wire or ribbon) is located. The wire specimen is attached to terminals which enable an electric current to be passed through it; temperatures up to 2300° F. may be thus obtained. The bakelite cassette transmits the *K* radiation from the target quite readily, but absorbs scattered radiation. The temperature of the specimen is observed by means of an optical pyrometer sighted through a small window in the bakelite tube. A good diffraction pattern may be obtained after an exposure of 10–15 min. Examples of diffraction patterns, at high temperatures, of 0·10% carbon steel and 12% and 16% chromium steel are reproduced.

Intensity of the Stray Radiation during X-Ray Irradiation. O. Vaupel. (Archiv für das Eisenhüttenwesen, 1935, vol. 9, Oct., pp. 213–214). A brief account is given of a research on the dependence of the strength of stray radiation during X-ray exposures on the distance from the surface irradiated, the angle between the stray beam and the incident X-ray beam, the size of the surface irradiated, the distance between the X-ray tube and the irradiated surface, and the tube voltage. A formula is given for calculating the strength of the stray radiation. The question of protection against stray radiation is touched upon.

Detection of Metallurgical Phenomena by Radioactive Methods. O. Werner. (Zeitschrift für Metallkunde, 1935, vol. 27, Sept., pp. 215–219). The author gives a qualitative picture of the diffusion of radium-emanation through the lattice of radium-bearing metals.

He shows that the temperature coefficient of the emanation-power of various metals is inversely proportional to the characteristic temperature of the Debye theory of solid bodies. Apart from allotropic transformations (dealt with by reference to thalium and iron), transformations in the homogeneous phase, such as the magnetic transformations (in iron and nickel) can also be registered by means of emanation-power/temperature curves. The course of the sintering of compressed metallic powders can also be investigated by measuring the emanation-power; compressed nickel and molybdenum powders are cited as examples.

The Detection of Oxide Inclusions in Steels by a Printing Method. R. Mitsche. (Berg- und Hüttenmännisches Jahrbuch, 1935, vol. 83, Dec. 23, pp. 127–133). In the method of making " prints " proposed by Niessner for the detection of iron oxide inclusions, gelatin paper is soaked in 1 : 20 hydrochloric acid, and then pressed (not too wet) on to the steel surface; it is then " developed " in ferrocyanide solution (20 g. of salt per litre). The present author's tests have shown that the method is satisfactory for revealing iron oxide inclusions in an iron ground-mass; differentiation of the mode of combination of the iron in the inclusions, however, is not possible. Reference is made to a number of points on which further information is necessary, such as the determination of the minimum amount of iron in the inclusions, and of the smallest size of particle that can be detected, and the influence of the quality of the gelatin paper and of the conditions of the " development " process. The reactions during the formation of the " print " are discussed.

Effect of Oxygen and Nitrogen on the Occurrence of Veining in Ferrite. W. Eilender and H. Cornelius. (Archiv für das Eisenhüttenwesen, 1935, vol. 9, Nov., pp. 263–264). In a series of tests on the purest iron with various contents of nitrogen and oxygen, no connection between the degree of veining in the ferrite and the nitrogen and oxygen contents could be found. The experiments point to a relation between the occurrence of the α-veining and stresses caused by the γ–α transformation. The impurities would appear to be of only subordinate importance.

Statistical Investigations of Structure. I. E. Scheil. (Zeitschrift für Metallkunde, 1935, vol. 27, Sept., pp. 199–208). The author deals with the application of statistical analysis to the investigation of metallographic structure.

Relation between Diffusion and Structure of Solid Alloys. W. Seith and A. Keil. (Zeitschrift für Metallkunde, 1935, vol. 27, Sept., pp. 213–215). The authors present a general discussion of the relation between the structure and condition of solid solutions on the one hand and the mobility of the atoms in the lattice structure on the other; the influence of temperature, the nature of the " partner," concentration, lattice type and recrystallisation is considered, and the possibility of electrolytic transportation in solid alloys is indicated. In regard to the latter, the authors

carburised iron wire sectionally, and then heated it for 10 hr. at 1070° C. *in vacuo* by passing a heavy current through it; the carbon diffused in the iron, but whereas with alternating current the diffusion was equal in both directions, with direct current the carbon moved towards the cathode.

The Recrystallisation above the Critical Temperature of Electrolytic Iron. G. Wassermann. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1935, vol. 17, No. 17, pp. 203–206). The recrystallisation of electrolytic iron differs radically from that of Armco iron and low-carbon steel; cold-worked electrolytic-iron sheet, when heated to a temperature below A_3, recrystallises in small grains, but if heated above the critical point the grain-size is coarse. By quenching from the γ condition the size of the crystals is reduced slightly. If the electrolytic-iron sheet is cooled from the γ condition in a temperature gradient, so that the transformation temperature "travels" along the specimen, small columnar crystals are formed—the slower the cooling the more complete their development; in explanation it is stated that the number of α crystal nuclei at the γ–α transformation is very small, and only increases as the undercooling becomes greater.

A New Method for the Determination of Transformation Points. H. Nipper and E. Lips. (Zeitschrift für Metallkunde, 1935, vol. 27, Oct., pp. 242–243). The authors describe a new method of determining those constitutional changes with which are associated changes in the strength properties of the materials. In a specially devised apparatus the torsional properties of the specimen are observed while the temperature is steadily raised; the change points are indicated by deviations in the time/torsional-angle curve.

Cinematographic Record of the $\alpha \rightleftharpoons \gamma$ Iron Transition, as seen by the Electron-Microscope. W. G. Burgers and J. J. A. Ploos van Amstel. (Nature, 1935, vol. 136, Nov. 2, p. 721). E. Brüche and W. Knecht have previously described a method of observing the $\alpha \rightleftharpoons \gamma$ change by means of the electron microscope; the emission of the test-piece at 900° C. was so small, however, that only a weak image on the fluorescent screen was obtainable. The present authors were able to obtain a bright image even at temperatures below 900° C., and they found it possible to secure a cinematographic record of the transition process. Six photographs are reproduced showing the change in structure during the transition period, and the growth of α-crystals in the original γ-phase.

Investigations on the Heat Evolution at Metallic Transformations. III.—Iron. H. von Steinwehr and A. Schulze. (Physikalische Zeitung, 1935, vol. 36, pp. 419–423). By a specially worked-out method, the heat evolutions at the A_2 and A_3 points were determined on pieces of vacuum-melted electrolytic iron (99·97%) weighing about 18 kg. The values obtained were $4{\cdot}8 \pm 0{\cdot}2$ cal. per g. at A_2 and $6{\cdot}2 \pm 0{\cdot}08$ cal. per g. The characteristic difference

between these two types of transformation could be recognised clearly from the calorimetric indications.

A Peculiar Phenomenon at Transformations which Extend over a Temperature Range. A. Schulze. (Zeitschrift für Metallkunde, 1935, vol. 27, Nov., pp. 251–255). From the observations recorded by the author it would appear that, in analogy with the case of gold-copper alloys, at temperatures below those of transformations which extend over a temperature range, anomalies occur in the curves of the properties of the materials which are very probably related to the actual transformations or in some way initiate them or pave the way for them. This is shown for the magnetic transformation in nickel, a few nickel alloys and iron, as well as for the transformation in β-brass, where transition from the ordered to the disordered atomic arrangement is assumed to take place, by means of measurements of the electrical resistance and its temperature coefficient, and the thermal expansion, and by taking cooling curves. While the anomaly in the property curves for β-brass occurred at about 160° C. below the commencement of the transformation, in nickel it was about 100° C., in iron about 50° C., and in nickel alloys about 100–130° C. below the start of the magnetic transformation. No explanation of the facts recorded can be offered.

Constitution and Properties of Some Iron-Carbon-Beryllium Alloys. M. Ballay. (Académie des Sciences, Nov. 22, 1935: Génie Civil, 1935, vol. 107, Dec. 14, p. 572). The alloys studied contained 3·0–4·45% of carbon and 0–4% of beryllium (manganese and silicon, 0·25% each; sulphur and phosphorus, low); they were cast in round bars in dry-sand moulds. Fe–C alloys of this group solidify in the metastable cementite system without the formation of graphite, even at cooling rates much slower than those used in these tests. Additions of 1·2–1·7% of beryllium increased greatly the apparent amount of cementite and a complex iron-beryllium carbide was observed. The amplitude of the cementite anomaly, at 210° C., diminished very much and became a function of the amount of pearlite only. The hardness values were high; for an alloy with 4·32% of carbon and 1·7% of beryllium the Vickers (50-kg.) hardness was 800, and increased to 935 on quenching from 950° C. in oil, which transformed the pearlite into martensite. With higher beryllium contents a constituent was observed, consisting of small grey particles, either granular or with polygonal contours; it was etched by boiling water, but after heating to about 900° C. in an oxidising medium it was no longer attacked, being probably protected by a thin layer of oxide. Its properties appear to relate it to the beryllium carbide Be_2C; that these two substances are identical may be assumed, although that found in Fe–C–Be alloys may contain a little iron. In certain alloys the beryllium carbide is accompanied by pearlite and a little secondary cementite; with sufficient beryllium no complex primary carbide exists. Other alloys, of more complex constitution and not in physico-chemical equilibrium, contained

beryllium carbide, complex carbide of iron and beryllium and pearlite; in the latter, dilatometric analysis indicated the presence of Fe_3C and not of iron-beryllium carbide, while oil-quenching from 950° C. had no other effect than to convert the pearlite into martensite, Be_2C apparently being little or not soluble in austenite, at least at the temperatures attained. The position of the Ac transformation was but little affected by beryllium under the conditions of the author's tests. While beryllium appears to combine with carbon (first as a complex cementite and then as a carbide with little or no iron), yet the addition of very small quantities to a white iron caused the appearance of graphite in the alloy. This graphitising action of small quantities of beryllium in alloys with only traces of silicon may be attributed to the strong reducing action of the element on the oxygen which would exist in combination or in solution in the iron; it is also possible that the formation of very finely divided beryllium oxide may initiate the graphite crystallisation during cooling by inoculation.

The System Iron/Cementite/Manganese-Carbide/Manganese. R. Vogel and W. Döring. (Archiv für das Eisenhüttenwesen, 1935, vol. 9, Nov., pp. 247–252). The constitutional diagrams for the systems manganese/manganese-carbide and iron/cementite/manganese-carbide/manganese were drawn up on the basis of thermal and microscopic investigations. Contrary to the opinion of previous workers, manganese and manganese carbide (Mn_3C) do not form an uninterrupted series of solid solutions with a temperature maximum; with 1·5–2·9% of carbon, a transition equilibrium occurs on cooling, which leads to a temperature minimum with higher carbon contents. Further, a transformation of the manganese carbide at 1050° C. was observed. For the three-component system it was found that with up to about 60% of manganese the conditions were the same as those for the marginal iron-carbon system. With higher manganese contents the conditions become more complicated; as a result of the transformations of the manganese and the manganese carbide, four four-phase planes occur, of which three are transition planes, whilst the fourth corresponds to a ternary eutectoid decomposition.

The Iron/Cobalt/Cobalt-Silicide/Iron-Silicide System. R. Vogel and K. Rosenthal. (Archiv für das Eisenhüttenwesen, 1935, vol. 9, Dec., pp. 293–299). The Fe–Co–CoSi–FeSi region of the iron-cobalt-silicon ternary system has been investigated thermally and microscopically, and with the aid of six sections through the silicon corner. The compounds FeSi and CoSi form together an uninterrupted series of solid solutions. A ternary compound of the composition FeCoSi is formed. The region investigated is divided into two partial fields (Fe–Co–Co_2Si–FeCoSi–FeSi and FeSi–FeCoSi–Co_2Si–CoSi). The crystallisation processes in the first field are delimited by five four-phase planes, of which two are transition planes, and two are eutectic planes, while the fifth corre-

sponds to a ternary eutectoid decomposition. In the second field the pairs in the opposite marginal systems resemble one another closely. As the marginal systems FeSi–CoSi and Co_2Si–FeCoSi form uninterrupted series of solid solutions, the three-phase equilibria of the Co_2Si–CoSi marginal system pass over into those of the system FeSi–FeCoSi.

Structures of Intermetallic Compounds of Beryllium with Copper, Nickel and Iron. L. Misch. (Zeitschrift für physikalische Chemie, 1935, Part B, vol. 29, pp. 42–58). An X-ray investigation was made of the compounds stable at room temperature of the systems Be–Cu, Be–Ni, and Be–Fe. In the Be–Cu system, two compounds were found: CuBe (with a lattice structure similar to that of caesium chloride) and $CuBe_2$ ($MgCu_2$ structure, face-centred cubic with 24 atoms in the elementary cube). In the Be–Ni system there were also two compounds: NiBe (body-centred cubic) and Ni_5B_2 (apparently of a deformed α-brass type). In the Fe–Be system two compounds, $FeBe_2$ and $FeBe_5$, were detected, and also another with a higher beryllium content, which, however, requires further study; $FeBe_2$ crystals are of the $MgZn_2$ type (hexagonal with 12 atoms in the elementary cube) and $FeBe_5$ crystals are of the same type as $MgCu_2$.

The Copper-Nickel-Iron System. W. Köster and W. Dannöhl. (Zeitschrift für Metallkunde, 1935, vol. 27, Sept., pp. 220–226). On the basis of data contained in the literature and their own magneto-metric, conductivity, and thermo-analytical determinations, the authors have constructed a three-dimensional constitutional model for the copper-nickel-iron system; the results of measurements of the physical properties are also recorded in triangular diagrams. The limit of the alloys which take part in the α–γ transformation runs from 28% of nickel on the iron-nickel side to the copper corner. The miscibility gap in the iron-copper system is closed up by the addition of nickel.

Data on the Iron-Tantalum Binary System. W. Jellinghaus. (Technische Mitteilungen Krupp, 1935, vol. 3, Nov., pp. 214–215). Little appears to be known about this system. The author has made a preliminary survey; six melts, with 6, 10, 15, 25, 50, and 75% of tantalum (using carbonyl iron), were made, and on the basis of the examination of the microstructure, the magnetic saturation, and the lattice structure, he has drawn up a sketch of the equilibrium diagram.

CORROSION OF IRON AND STEEL

Investigations on the Anodic Behaviour of Corrosion- and Heat-Resisting Iron Alloys. L. Harant. (Berg- und Hüttenmännisches Jahrbuch, 1935, vol. 83, Dec. 23, pp. 122–127). By means of current-density/potential curves and quantitative solution tests, the process of the dissolving of anodes made of various corrosion-resistant alloys was investigated. The agreement between specimens of approximately similar composition and structure was very good. It was found that after passivification had occurred the solubility depended on the current density applied, and that at medium potentials there was a sharply defined range within which complete solubility could be present.

Metals in Wineries. C. S. Ash. (Industrial and Engineering Chemistry, 1935, vol. 27, Nov., pp. 1243–1244). In this article an account of the behaviour of ferrous and non-ferrous metals subjected to the corrosive action of wine or vinegar is given. The nickel-chromium steels of the 18/8 type were found to be the best for vessels containing wine, vinegar, or fruit juices, although for pumps a silicon cast iron (such as Duriron) is more suitable. The non-ferrous metals are not very satisfactory, but nickel behaves fairly well; copper and its alloys, and most other non-ferrous metals, tend to contaminate the wine. Wrought iron and steel are apt to corrode, but in many cases the tannin present in the wine forms a protective coating of iron tannate which inhibits further action. However, the use of iron and steel is not recommended. Cast iron may or may not corrode rapidly—its behaviour is somewhat erratic.

Report on Protective Coatings for Underground Pipes. A. B. Densham and F. C. Smith. (Institution of Gas Engineers, 1935, Communication No. 115). This article is a summary of a report on the above subject, and deals mainly with soil corrosion and electrolytic corrosion. The report describes accelerated tests which have been developed to test the efficacy of various protective coatings; some of these coatings are discussed. The relative corrodibilities of steel and wrought iron were investigated; in this connection field experiments lasting $2\frac{1}{2}$ years were carried out.

MINERAL RESOURCES

Notes on the Geology and Coals of the South Wales Coalfield. F. J. North. (South Wales Engineering Exhibition, Supplement to Colliery Guardian, 1935, vol. 151, Nov. 15, pp. 35–40). The South Wales coalfield is roughly oval in shape, its length from east to west being about 90 miles and its greatest breadth 16 to 20 miles. The Coal Measures occur in the local sandstone and shale beds; carboniferous limestone and millstone grit are present, but do not contain coal. Upper and lower Coal Measures are distinguishable; the former yield house and bituminous coal, but the latter are more varied—they change from bituminous coals in the east to anthracites in the west, along the northern margin of the field, although the coals on the southern edge are not anthracitic. The coals may conveniently be classified on the basis of the C/H ratio (the carbon/hydrogen ratio). The C/H ratio increases from east to west and from higher to lower seams. Several hypotheses have been advanced to explain the occurrence of anthracite in the South Wales measures, none of them entirely conclusive; it seems clear that in any case the change responsible for the difference in the character of the measures must have occurred independently of the folding of the strata which subsequently took place.

The Fossils and Geological History of the South Wales Coal Measures. F. J. North. (Proceedings of the South Wales Institute of Engineers, 1935, vol. 51, Dec. 27, pp. 271–300). This paper constitutes a survey of the lithological and palæontological features of the Coal Measures of South Wales.

The South Wales Coals. J. W. Fidoe. (Engineering and Boiler House Review, 1936, vol. 49, Jan., pp. 506–508). The author describes first the extent, geological age, and formation of the coal deposits of South Wales, and follows this with an indication of the quality, price, and size of the grades produced, the areas in which the coal is marketed, and the uses for which they have been found most satisfactory. Attention is chiefly directed to the anthracites.

The Brown Coal Deposit at Yallourn, Australia, and its Utilisation. J. Henderson. (Journal of the Chemical, Metallurgical and Mining Society of South Africa, 1935, vol. 36, Nov., pp. 130–134). It is estimated that there are six thousand million tons of brown coal in the Yallourn area. The thickness of the seam now being worked is 180 ft.; it lies beneath a sandy overburden which averages 30 ft. The following is the average composition of the deposit: Moisture 64·0%, volatile hydrocarbons 19·4%, fixed carbon 15·9%, and ash 0·7%. The overburden is removed by a rotary dredge, and

the coal is quarried on two levels, also by dredges. Most of the coal is used to generate electric power for the city of Melbourne, and, ultimately, for the whole of the State of Victoria; the remainder is briquetted. The briquettes are made by crushing, screening, drying, cooling, and pressing the coal; no binder is used. They have the following composition: Moisture 14%, volatile hydrocarbons 42·4%, fixed carbon 41·75%, ash 1·85%.

India's Coal Resources (Being a Note on the Reserves Available in India of Good-Quality Coal Including Coking Coal). Sir L. L. Fermor. (Records of the Geological Survey of India, 1935, vol. 69, Part 3, pp. 336–352).

Investigations on the Manganese Ore Mining in Ilfeld. On the Possibilities of Recommencing Operations. G. Salzmann. (Zeitschrift für praktische Geologie, 1935, vol. 43, Nov., pp. 171–174). This article starts with a brief description of the manganese ore deposits at Ilfeld in the Southern Harz, Germany.

The Coal-Bearing Basin of Petschora. A. Matwéew. (Zeitschrift für praktische Geologie, 1935, vol. 43, Oct., pp. 145–150). The geology and coal deposits in the Petschora basin, lying between the Ural and Timan mountain ranges and bordering the Polar Sea, are described.

The Southern Alaska Range. S. R. Capps. (United States Geological Survey, 1935, Bulletin No. 862). The mineral resources of this region, including the coal and petroleum deposits, are described.

Geology of the Santa Rita Mining Area, New Mexico. A. C. Spencer and S. Paige. (United States Geological Survey, 1935, Bulletin No. 859). Particulars are given of the iron ore and zinc ore deposits in the State.

Pennsylvanian Coals of the South-Eastern Margin of the Western Interior Province. C. M. Young. (American Institute of Mining and Metallurgical Engineers, 1935, Contribution No. 92). The author discusses the coal-forming conditions obtaining during the Pennsylvanian period, formerly known as the Upper Carboniferous, in the Western Interior Coal Province. A few of the more important details of the coalfields in this Province, which includes Iowa, Missouri, Kansas, Oklahoma, and Arkansas, are discussed.

The Mineral Wealth of Abyssinia. O. Günther and F. Hermann. (Zeitschrift für praktische Geologie, 1935, vol. 43, Nov., pp. 161–167). The ore and other deposits of Abyssinia are reviewed. Iron and manganese ores are said to occur in the Ghedem mountain and in the region of Chelga; analysis of the ore from the latter source revealed 39·5% of iron.

China's Coal Reserves. J. H. Schultze. (Zeitschrift für praktische Geologie, 1936, vol. 44, Jan., pp. 15–16). The coal reserves of China are discussed and compared with those of Siberia and Japan. Estimates of the extent of the reserves, as also of those in some of the individual provinces, appear to vary widely.

ORES—MINING AND TREATMENT

(Continued from p. 2A)

The Roasting and Sintering of Dust and Powdery Ores in the Saint-Jacques Turbulent Furnace. C. Saint-Jacques and L. Poupet. (Seventh International Congress on Mining, Metallurgy and Applied Geology, Paris, Oct., 1935: Revue de Métallurgie, Mémoires, 1935, vol. 32, Nov., pp. 581–588). **Treatment of Iron Ore Fines.** (Iron and Coal Trades Review, 1935, vol. 131, Dec. 13, pp. 982–983). The Saint-Jacques sintering furnace is illustrated and described. (*See* Journ. I. and S.I., 1935, No. II., p. 325).

The Sintering and Reduction of Krivoi-Rog Ores. M. Schönzeler. (Stahl und Eisen, 1936, vol. 56, Jan. 9, pp. 47–49). A short review is presented of two papers, one by S. T. Rostowzew and S. M. Mejerow on the sintering of Krivoi-Rog ores (Domes, 1934, vol. 6, No. 11–12, pp. 7–39), and the other on the reducibility of these ores (*ibid.*, pp. 45–50).

Sintering Hematite Ore. (Iron and Steel Industry, 1936, vol. 9, Jan., pp. 140–142). A description of the sintering plant installed at the works of the Millom and Askam Hematite Co., Ltd., is presented. The A.I.B. system is in use, and the daily capacity of the eight pans is 500 tons.

Separation of Hematite by Hysteretic Repulsion. E. W. Schilling and H. Johnson. (American Institute of Mining and Metallurgical Engineers, 1935, Technical Publication No. 654; Metals Technology, 1935, vol. 2, Dec., No. 8). Details of experiments conducted on the separation of hematite by hysteretic repulsion are recorded. The behaviour of specular hematite was studied in the first place. A three-pole magnet energised by three-phase current, connected in delta, was adopted. The effects of varying the air gap, inducing vibration, altering the frequency of excitation, and submitting the material to a reducing heat treatment were studied. The behaviour of red hematite was also examined. Definite values of the air gap and frequency of excitation were discovered which gave optimum separation of the hematite. Vibration had the effect of augmenting the amount of hematite separated. When the specular hematite was subjected to a reducing heat treatment in hydrogen at 500° C. for 30 min. the reduced ore became magnetic, and was much more active under the influence of an alternating field than when in the unreduced state. Preliminary D.C. magnetisation of the reduced material still further increased the activity of the hematite. Tests on red hematite showed it to be practically unaffected in the untreated condition, but when subjected to heat treatment, or to a combination of heat treatment and preliminary D.C. magnetisation, the particles showed marked activity. In conclusion, the authors briefly describe an experimental separator.

FUEL

(Continued from pp. 42 A–46 A)

Analyses and Softening Temperatures of Coal Ash. D. J. Jones and E. L. Buller. (Industrial and Engineering Chemistry, 1936, Analytical Edition, vol. 8, Jan. 15, pp. 25–27). Data on the analyses and softening temperatures of the coal ash from coals in the northern anthracite field of Pennsylvania, U.S.A., are presented.

Flame Gases in the Light of Recent Research. W. T. David. (Proceedings of the South Wales Institute of Engineers, 1936, vol. 51, Jan. 23, pp. 375–388). It is shown that there exists a long-lived latent energy in flame gas, and that it varies in amount with (1) the nature of the combustible gas, (2) the pressure at which combustion takes place, and (3) the nature of the diluent gases. The possible nature of this latent energy is suggested.

Steel-Melting Furnaces. A. J. Boynton. (Iron and Steel Engineer, 1936, vol. 13, Jan., pp. 25–26). The advantages of adopting automatic control of the roof temperature, air/fuel ratio, and reversing cycle in open-hearth furnaces are shortly enumerated.

Heat Exchanges by Convection. Ribaud. (Chaleur et Industrie, 1935, vol. 16, Dec., pp. 537–542). The author discusses the thermodynamics of heat exchange by convection.

Some Historical Notes on the Metallic Recuperator. Damour. (Chaleur et Industrie, 1935, vol. 16, Dec., pp. 544–548). After touching on older types of industrial air preheaters, the author reviews the development of the modern metallic recuperator.

Continuous Metallic Air Preheaters. Modern Construction on Furnaces. R. Martin. (Chaleur et Industrie, 1935, vol. 16, Dec., pp. 548–551). After comparing briefly the advantages and disadvantages of metallic and refractory recuperators, the author presents data regarding a number of continuous metallic air preheaters attached to various types of furnaces, including a pulverised-fuel-fired rotary furnace for melting cast iron and a heavy-oil-fired rotary furnace for steel-melting.

Natural Cooling and Recovery of Heat in Continuous Electric Furnaces. M. Hartenheim. (Industrial Heating, 1935, vol. 2, June, pp. 299–300; July, pp. 351–352; Aug., pp. 403–404; Dec., pp. 703–706). The application of the principle of recuperation to the recovery of heat in continuous electric furnaces is dealt with. Formulæ are developed and applied for calculating the natural cooling and heat recuperation under different conditions. Examples of the application of these formulæ are furnished.

Microscopic and Petrographic Studies of Certain American Coals. R. Thiessen and G. C. Sprunk. (United States Bureau of Mines, 1935, Technical Paper No. 564). The authors report work on

the petrography and microscopy of six coals studied in connection with the Bureau of Mines work on the carbonising properties and constitution of American coals.

The Cleaning of Coal Using Dense Media. R. A. Mott. (Institute of Fuel, Jan. 22, 1936 : Colliery Guardian, 1936, vol. 152, Jan. 24, pp. 153–158 : Iron and Coal Trades Review, 1936, vol. 132, Jan. 24, p. 190). The chief features of the coal-washing processes in which dense media are used are critically examined. Among the systems considered are the Chance method, the Clean Coal Co. process, and the Barvoys (de Vooys) system.

Dedusting of Coal. G. Lindley. (Institute of Fuel, Jan. 8, 1936 : Colliery Guardian, 1936, vol. 152, Jan. 17, pp. 108–109 : Iron and Coal Trades Review, 1936, vol. 132, Jan. 24, p. 182). The paper outlines the various dedusting systems, including the Pfeiffer, Simon-Carves, Sherwood Hunter, Birtley, All-Bec, and Lessing processes. The author goes on to review the benefits obtained from dedusting and the uses to which the dust may be put.

Dust-Collecting Plant at Parsonage Colliery. (Iron and Coal Trades Review, 1936, vol. 132, Jan. 3, pp. 13–15). The dust-collecting plant installed on the screening equipment at the Parsonage Pit of the Wigan Coal Corporation, Ltd., is described.

Fusain Content of Coal Dust from an Illinois Dedusting Plant. G. Thiessen. (American Institute of Mining and Metallurgical Engineers, 1935, Technical Publication No. 664). The very fine dust, below 200 mesh, produced during the preparation of coal, is composed mainly of fusain, and may serve as a convenient source of fusain on a large scale. A concentrate rich in fusain may be obtained (1) by recovering the dust in the last of several consecutive stages, or (2) by sizing recovered dust by screening or air separation.

Blackwell Colliery By-Product Coking Plant. (Coal Carbonisation, Supplement to Colliery Engineering, 1936, vol. 2, Jan., pp. 5–12). In addition to the forty coke ovens formerly built, the Blackwell Colliery Co., Ltd., have recently installed eighteen Koppers regenerative combination ovens which may be fired by coke-oven gas or producer gas.

A Study of Indian Coals with Special Reference to their Coking Properties. K. Bunte, H. Bruckner and J. Sanjana. (Fuel in Science and Practice, 1935, vol. 14, Dec., pp. 350–363). The authors report the results of an investigation on the properties (especially the coking properties) of Indian coals. They give data for the proximate and ultimate analyses, the softening and fusion points of the ashes, and the softening and fusion temperatures of various blends of coal; the results of caking tests and extraction tests are also recorded. Then follows an account of some low-temperature carbonisation tests and of tests used for determining the softening range and evolution of volatile matter.

Carbonisation of Coal-Oil Mixtures. D. Brownlie. (Iron and Coal Trades Review, 1936, vol. 132, Jan. 17, pp. 98–99). The principal methods of carbonising coal-oil mixtures which have been proposed, or which are actually in operation, are reviewed.

The Results of Low-Temperature Carbonisation of Some Lower Gondwana Indian Coals. Sir L. L. Fermor. (Records of the Geological Survey of India, 1935, vol. 69, Part 3, pp. 353–360).

The Reactivity of Coke. D. A. Reynolds and J. D. Davis. (Industrial and Engineering Chemistry, 1936, Analytical Edition, vol. 8, Jan. 15, pp. 33–36). An improved method for determining the reactivity of coke in carbon dioxide is described in detail, and some results of reactivity tests are reproduced. The reactivity of coke from a given coal was found to decrease with increase in the carbonising temperature.

Open-Hearth Furnace Operation. E. H. Schwartz and G. E. Rose. (Iron and Steel Engineer, 1936, vol. 13, Jan., pp. 1–7). The authors discuss the performance of open-hearth furnaces fired with a mixture of coke-oven and blast-furnace gas. They present some results obtained from mixed-gas-fired furnaces which yielded a fuel economy of 4,000,000 B.Th.U. per ton of steel produced, and show that, as with oil-firing, the performance of the furnace is improved if movable ports are fitted. Emphasis is placed on the high heat transfer efficiency attainable with mixed-gas firing, and the necessity of reducing air infiltration to a minimum.

The Question of the Available Gas Reserves of the Coke-Oven Plants of the Ruhr District. O. Dünbier. (Berg- und Hüttenmännisches Jahrbuch, 1935, vol. 83, Dec. 23, pp. 113–115). The author reviews and discusses the production and utilisation of coke-oven gas in the Ruhr from the viewpoint of long-distance gas supply.

Flow of Natural Gas Through High-Pressure Transmission Lines. T. W. Johnson and W. B. Berwald. (United States Bureau of Mines, 1935, Monograph No. 6). Pipe-line formulæ used by different investigators are given, and the results of flow tests on commercial and experimental pipe-lines are discussed. The application of flow data to commercial pipe-line transmission problems is also dealt with.

The Hydrogenation of Coal at the English Works at Billingham of Imperial Chemical Industries, Ltd. C. Berthelot. (Génie Civil, 1935, vol. 107, Dec. 7, pp. 531–539).

Study of the Use of Liquid Fuels for Heating. Test on a Compressed-Air Atomising Burner. M. Steffes. (Revue Technique Luxembourgeoise, 1935, vol. 27, Sept.–Oct., pp. 81–84). A short discussion of fuel oils and their use for firing boilers, followed by notes on a test carried out on a Cuénod type of atomising burner, in which the fuel oil is atomised by the compressed air for combustion and the air–oil mixture is automatically controlled.

PRODUCTION OF IRON

(Continued from pp. 47A–49A)

The Electric Rotary Clay Gun. (Iron and Steel Industry, 1936, vol. 9, Jan., pp. 145–146). The electric clay gun, which is described, consists of a barrel in which two electrically-driven screws work, forcing the clay into the tap-hole. The gun is mounted on a carriage pivoted on a pedestal, also electrically driven. It is possible to close the tap-hole against the full air-blast pressure, with the use of this gun.

Production and Preparation of Blast-Furnace Flux. R. C. Hodges. (American Institute of Mining and Metallurgical Engineers, 1936, Technical Publication No. 668; Metals Technology, 1936, vol. 3, Jan., No. 1). An account of the method of quarrying, milling and processing the Columbus limestone produced at Marble Cliff, Columbus, Ohio, is presented.

Some Engineering Aspects of the First Report of the Blast-Furnace Practice Sub-Committee. T. B. Mackenzie. (Journal of the West of Scotland Iron and Steel Institute, 1935, vol. 43, Nov., pp. 19–40). The author rearranges the data contained in the Report of the Blast-Furnace Practice Sub-Committee of the Iron and Steel Industrial Research Council, treating it under the headings of basic practice, hematite practice and foundry practice.

Five Years of Progress in Southern Blast-Furnace Practice. F. H. Crockard. (American Institute of Mining and Metallurgical Engineers, 1935, Technical Publication No. 653; Metals Technology, 1935, vol. 2, Dec., No. 8). An outline of the improvements in blast-furnace practice which have taken place in the iron- and steel-making districts of southern U.S.A. during the past five years is presented. The major developments include a reduction in the ash of the coke and improved structure and porosity, close sizing of the coke and ores, careful selection of the ores, wider stock lines, improved offtakes and downcomers and better furnace lines, wide-spread use of McKee distributors, the introduction of machine-casting, and an improvement in the physical characteristics of the iron. This development has given rise to a reduction in coke consumption from 3000 to about 2200 or 2300 lb. per ton, a reduction in the amount of flue-dust produced (from 300–250 to 50–100 lb. per ton), improved chemical analyses, a reduction in labour charges (owing to mechanisation) and improved physical appearance of the iron.

Some Problems in the Manufacture of Southern Merchant Pig Iron. F. H. Crockard. (Metals and Alloys, 1935, vol. 6, Nov., pp. 318–321).

Investigations on the Reduction Conditions and Experiments with Pre-reduced Sinter in a Charcoal Blast Furnace at Sandviken. M. Wiberg. (Jernkontorets Annaler, 1935, vol. 119, No. 12, pp. 499–548). A charcoal blast-furnace was used, first to study the reduction conditions when using sinter containing 55% of iron, and subsequently to investigate the behaviour of sinter pre-reduced in a shaft furnace and smelted in the blast-furnace. When pre-reduced sinter was used, the CO_2 content of the blast-furnace gas decreased from 13·5% to 9·4%, and the consumption of charcoal increased slightly. The pre-reduced sinter was observed to be less easily reduced than ordinary sinter—probably because the latter disintegrates more readily, giving a greater reacting surface.

Machine-Cast Pig Iron. J. Dale. (Iron and Steel Industry, 1935, vol. 9, Dec., pp. 86–89). At the Workington branch of the United Steel Co. a pig-casting machine is in operation, consisting of two strands of cast-iron moulds (one of 300 and the other of 292 moulds); this is to allow each strand to have its own chute, thus making the delivery of the pigs easier. The moulds are carried on an endless chain, from which they may be readily detached for replacement. The speed of the machine can be varied from 20 to 35 ft. per min., and permits pigs varying in weight from 28 to 110 lb. to be poured. During their return from the delivery end the moulds are sprayed with lime-wash by means of steam jets. One of the salient features of the installation is the method of pouring the metal. The molten metal is poured from ladles which have a very short pouring distance from ladle to launder; this obviates the splashing which has hitherto militated against the adoption of casting machines.

Modernising a Wrought Iron Works. J. Long. (Iron and Steel Industry, 1936, vol. 9, Jan., pp. 142–144). Some of the ways in which a wrought iron works may be modernised are suggested; they include the use of electric drive to the mills, insulating the mill furnaces, and applying automatic control to the gas producers.

Sponge Iron. (Foundry Trade Journal, 1936, vol. 54, Jan. 16, p. 73). In the new German process which is described, iron ore is briquetted (with a small amount of carbon if necessary) and reduced with CO, hydrogen, or other suitable gas in a shaft furnace. The ore reaches its highest temperature about halfway down the furnace, being then cooled almost to atmospheric temperature by a cold blast of reducing gas admitted at the base of the furnace, where the sponge iron is extracted.

FOUNDRY PRACTICE

(Continued from pp. 50 A–55 A)

A Comparison of Some Melting Furnaces in a Grey-Iron Foundry. T. R. Twigger. (Institute of British Foundrymen: Foundry Trade Journal, 1936, vol. 54, Jan. 2, pp. 3–6). The author discusses the various types of furnace used for melting grey iron. They include the cupola, rotary furnaces fired with oil or pulverised fuel, crucible furnaces, and electric furnaces; the chief features of each type of unit are described.

The Balanced Blast Cupola. W. Y. Buchanan. (Institute of British Foundrymen: Foundry Trade Journal, 1936, vol. 54, Jan. 16, pp. 69–72). A detailed account of the performance of some cupolas, which were converted to balanced blast operation and continuous pouring, is given.

Adopts Test Block Control. H. P. Biegel. (Foundry, 1935, vol. 63, Nov., pp. 31, 82). In order to determine the quality of cupola iron the author has devised a test which is based on the silicon content of the iron and its effect on the depth of chill of a quenched chill specimen. A small test block is poured in an open mould, with the narrow face against the chill. When the block has cooled to a dark red it is quenched in oil, and subsequently in water. The quality of the iron is indicated by the appearance of the fracture.

Progress Made in the Development of Quality Cast Irons and the Manufacture of High-Duty Castings. L. F. Girardet. (Bulletin de la Société d'Encouragement pour l'Industrie Nationale, 1935, vol. 134, Oct.–Nov., pp. 561–570). Progress made in the production of better-quality casts is due to knowledge of the structure of the metal and of the conditions for obtaining the best structure. The author discusses the graphite and matrix of cast iron and the bad effect of gases. He demonstrates the necessity for bringing the metal into a condition of stable physico-chemical equilibrium, and indicates how it can be done quickly and with certainty; he touches on the mechanical method by stirring, and then describes the chemical method by means of soda ash; he discusses the results obtained by each method, and points out the advantages of combining the two systems. Finally, he describes a simple appliance by which the metal can be agitated with soda ash in the ladle.

The Expansion and Contraction of Moulding Sand at Elevated Temperatures. H. W. Dietert and F. Valtier. (Transactions of the American Foundrymen's Association, 1935, vol. 6, Dec., pp. 107–122). The authors investigated the contraction and expansion of moulding sands, and found that the fineness, clay content, amount of sea coal added, and mould hardness exert important effects on

those two properties. They explain that moulding sands with improper expansion and contraction properties are often responsible for such defects as rat-tails and scabs. The authors describe the apparatus used for determining the expansion and contraction of moulding sands, and indicate the ways in which these properties may be controlled.

Core-Room Layout Features English Automobile Foundry. V. Delport. (Foundry, 1935, vol. 63, Dec., pp. 26–28, 71–72). The arrangement of the core-making department at the foundry of the Austin Motor Co., Ltd., is outlined.

Continuous Pouring of Ford Cylinder Blocks. E. F. Cone. (Metals and Alloys, 1935, vol. 6, Nov., pp. 299–302). At the Rouge Plant of the Ford Motor Co. continuous pouring of cylinder blocks is adopted. The first step is to run molten pig iron from the blast-furnaces, and cast iron from a battery of cupolas, into a 400-ton mixer. The cupola charge may contain 15% or more of steel scrap, and the quantity of pig iron from the blast-furnaces may amount to 40 or 45% of the charge to the mixer. The proportions are so adjusted that an iron of the correct composition is obtained, which is as follows: Carbon 3·15–3·35, manganese 0·60–0·80, silicon 1·80–2·10, sulphur 0·100 max., phosphorus 0·25–0·32 and copper 0·50–0·75%. The hot metal is transferred by means of a ladle to a 20-ton electric furnace. At intervals of 20–30 min. the now superheated metal is poured into a 25-ton air furnace, fired with pulverised coal. From the air furnace the metal flows into two pouring ladles continuously, while the ladles deliver metal to the moulds as they travel by on the conveyor line. The introduction of the air furnace as a reservoir of molten iron is said to confer closer control of the temperature of the iron, an increase in the effective capacity of the electric furnace of 100%, better control of the quality of the metal, and an increase in the number of moulds poured per day.

Progress in the Production of Cast Iron for Locomotive Parts. A. Reyburn. (Transactions of the American Foundrymen's Association, 1935, vol. 6, Dec., pp. 151–160). Failures of locomotive cylinders used on the locomotive equipment of the Canadian railways led to attempts to improve the quality of the cast iron used. The author outlines the types of irons adopted for such parts as cylinders, cylinder liners, valve bushings, pistons, bull-rings, and packing-rings, and summarises the general moulding and core-making practice for cylinders. The use of nickel and nickel-chromium cast iron has, in several instances, increased the life of the parts and enabled useful savings in cost to be effected.

Moulding a Branch Pipe in Greensand. J. W. Molder. (Iron and Steel Industry, 1935, vol. 9, Dec., pp. 94–95). The points to be observed when moulding a branch pipe in greensand are explained.

Recent Developments at the Dagenham Foundry of the Ford Motor Co., Ltd. V. C. Faulkner and J. N. Burns. (Institute of

British Foundrymen: Foundry Trade Journal, 1935, vol. 53, Dec. 26, pp. 465–466). The authors present some further details of the foundry practice at the Dagenham Works of the Ford Motor Co. They describe the coke-oven-gas-fired furnaces used for superheating the iron, of which there are now two in operation, each of 5 tons capacity. The furnaces work on the duplex system and take liquid metal from the cupola. The cold charges are put through the cupola at the rate of 5 tons per hr., and the molten metal is run into a forehearth from which it is transferred to the rotary furnaces. For crankshaft iron the charge consists of 50% back scrap, 35% pig iron, and 15% steel. Three types of crankshaft are being produced in this way. The moulding and pouring departments are fully mechanised, and the fettling department is being altered to suit the present production methods. A continuous malleable foundry is also in operation. (*See* Journ. I. and S.I., 1934, No. II., p. 552).

Pennsylvania Steel Foundry Produces Heavy Castings. P. Dwyer. (Foundry, 1935, vol. 63, Nov., pp. 22–26, 60, 62). The foundry of the Mesta Machine Co., West Homestead, Pa., which specialises in the production of rolls, rolling-mill machinery, forging and bending presses, and similar heavy castings, is described. Among the chief features of this foundry are the furnaces in the melting bay. These comprise eight hand-fired air-furnaces, ranging in capacity from 10 to 30 tons, for the melting of iron, a 60-in. cupola for the production of light castings, and four acid-lined open-hearth furnaces, one of 30 tons and the others of 40 tons capacity, in which the steel is melted.

PRODUCTION OF STEEL

(Continued from pp. 56 A–57 A)

Corby Works of Messrs. Stewarts and Lloyds Limited. (Blast Furnace and Steel Plant, 1935, vol. 23, Dec., pp. 842–848). (*See* p. 17 A).

Open-Hearth Steelworks in South Africa. (Demag News, 1935, vol. 9, Nov., pp. 33–37). An account of the open-hearth steel plant in operation at the works of the South African Iron and Steel Industrial Corporation, Ltd., Pretoria, is given.

Steel Industry Undertook Many Improvements in Plant Facilities during 1935. (Iron Age, 1936, vol. 137, Jan. 2, pp. 124–129). Details of the extensions to American steel plants carried out in 1935, or in progress, are recorded.

Improving Open-Hearth Furnace Design. W. C. Buell, jun. (Steel, 1935, vol. 97, Dec. 16, pp. 53–56; Dec. 23, pp. 45–48, 54). In these, the concluding instalments of the series, the author summarises the chief points dealt with in the previous articles. (*See* p. 56 A).

Terni Open-Hearth Furnace. (Iron and Coal Trades Review, 1935, vol. 131, Dec. 27, pp. 1073–1075). This is an English translation of an article by Göbel which appeared in Stahl und Eisen, 1935, vol. 55, Aug. 15, pp. 882–889. (*See* Journ. I. and S.I., 1935, No. II., p. 378).

Steelworks Furnace Equipment. H. Southern. (Iron and Coal Trades Review, 1936, vol. 132, Jan. 17, pp. 131–132). The trend of progress in the design of steelworks equipment is briefly reviewed; attention is given to developments in the thermal efficiency of open-hearth furnaces, furnace equipment for the reheating of ingots and billets, and forge furnaces.

Open-Hearth Roof Temperature. H. M. Schmitt. (Metals and Alloys, 1935, vol. 6, Dec., pp. 333–335). The measurement of roof temperatures by means of a thermocouple inserted (*a*) beneath the roof insulation, (*b*) in the roof itself, and (*c*) in a refractory insert in a water-cooled tuyere mounted in the roof is described, and the use of a radiation pyrometer sighted into a refractory tube built into the roof is dealt with.

Infiltered Air in Furnace Operation. H. Schwiedessen. (Archiv für das Eisenhüttenwesen, 1936, vol. 9, Jan., pp. 319–326). The infiltration of air into the hearth of furnaces is caused by low pressure in the hearth and pervious places in the furnace walls. This infiltered air reduces the temperature difference between the combustion gases and the charge, and increases the amount of waste gas; the result is a reduction of the furnace efficiency and an increased fuel consumption. The higher the degree of preheat

of the air for combustion to attain to higher flame temperatures, the greater is the influence of this unwanted air. The furnace part with the greatest influence on the low pressure in the furnace, and so on the amount of infiltration, is the chimney damper, to which particular attention should therefore be given. Another way of preventing infiltration is by keeping the furnace walls gas-tight and avoiding all superfluous openings and doors. Further, the shape of the furnace should be designed to reduce as much as possible differences of pressure due to buoyancy and frictional losses. In operation infiltration cannot be entirely avoided, but its adverse influence can be minimised by working with an excess of fuel gas or by introducing gas at the places where the infiltration is occurring. The discussion of the effect of air infiltration is amplified by reference to practical examples.

Modern Overhead Conveyors. Schulze-Manitius. (Giesserei, 1936, vol. 23, Jan. 3, pp. 11–14). Constructional details of modern overhead conveyors, such as are used for carrying materials and goods in works, are described and illustrated.

Comparative Investigations on the Action of Special Deoxidising Materials in Mild Steel. P. Zimmermann. (Mitteilungen der Kohle- und Eisenforschung G.m.b.H., 1935, vol. 1, No. 3, pp. 29–48). The author has investigated the action of various deoxidisers (Fe–Si, Ca–Si, feralsit, simanal, alsimin, Fe–Si + Al, and aluminium; approximate compositions stated) and their influence on the resulting steel; details of the steelmaking and the rolling of the ingots, &c., are given. The effects of the various agents are revealed primarily in the segregation, composition of the residue (in the chlorine method of analysis), the number, size, and arrangement of the non-metallic inclusions, the piping, and the tendency to ageing. Alsimin appeared to be the best deoxidiser; owing to the high silicon recovery in the heats treated with this material the killing action was very great, and the special properties of the metal must, in part, be attributed to this cause, yet, nevertheless, the alsimin must have had some favourable effect, as otherwise the high degree of killing would have been accompanied by a large quantity of non-metallic inclusions. That the alsimin-treated heats had the least pipe was probably due to the slow pouring speed necessitated by the viscosity of the steel. Alumina inclusions were unavoidable, owing to the comparatively high content of aluminium in the alsimin. Much the same can be said for simanal as for alsimin, particularly in regard to the low inclusion content despite the high degree of killing. With the exception of aluminium, the other deoxidisers had the usual known effects. Without regard to the degree of killing, all of them reduced the segregation. The inclusion "index" was higher for Fe–Si and Ca–Si than for the other materials; with Ca–Si the inclusions were almost entirely small and uniformly distributed, and despite the low silicon content in the steel it produced complete killing without the addition of

aluminium; by its use no diminution of the sulphur content of the steel was observed. Aluminium was the least satisfactory agent; the inclusions were most numerous and coarse, particularly at the lower end of the ingot, and their distribution was unfavourable, whilst the segregation was the greatest. The large occurrence of alumina inclusions and the marked piping associated with aluminium are known; the number of inclusions near the surface of the ingot, however, was the lowest. There was a heavy formation of skin holes, but this was probably accidental. The separate addition of aluminium and Fe–Si also had disadvantages in regard to the inclusions, segregation and blow-holes, though to a less extent than pure aluminium alone. In comparison with the unkilled heats, all those treated with killing agents had the disadvantages of the formation and retention of deoxidation products in the solid steel and a tendency to piping. No difference between the mechanical and the deep-drawing properties of the killed and unkilled steels was observed.

The Manufacture of Plain Carbon Steels in Top-Charge Rapid Type Furnace. W. B. Wallis. (Electrochemical Society, Oct., 1935, Preprint No. 33). The advantages of the top-charge type of electric steel furnace are enumerated and discussed at length. As compared with the older type of furnace, which was charged through a side door, there is a substantial saving in power, electrodes, refractories, and labour, due largely to the more rapid charging and shorter periods between two successive chargings of the top-charge type. The furnace roof of the new furnace is swung to one side during charging. Furnace capacities range from 5 to 20 tons. A 5-ton furnace consumes 2500 kWh. at 80% thermal efficiency.

Metallurgy of the Induction Furnace and the Production of Tool Steel. S. L. Roberton. (Metal Treatment, 1935, vol. 1, Winter issue, pp. 179–185). Recent work in Germany on the general features of the high-frequency induction furnace process, including the linings, reactions and melting technique, is reviewed.

Progress in Design and Application of Electric Furnaces. H. Knight. (Metallurgia, 1935, vol. 13, Dec., pp. 53–56). Some of the more recent developments in the application and design of electric furnaces are reviewed. These include the high-frequency furnaces installed at the works of Samuel Fox and Co., Ltd., Sheffield, the " Tocco " process of hardening by induced currents, the Fitterer-Savoie thermocouple, and the rocking-resistor furnace.

Finishing the Heat of Steel. J. H. Hruska. (Blast Furnace and Steel Plant, 1935, vol. 23, Oct., pp. 701–702; Nov., pp. 769–770; Dec., pp. 852–853). In the first article the author compares ingots and ingot moulds of the round, rectangular and polygonal types, and mentions sand-cast ingots. Hot tops and sink heads are next described, brief details of their construction and application being given. The third article treats of certain details of mould

design, including the fillets, chamfers, flutes and corrugations used.

Gaseous and Solid Impurities in Ingots. J. H. Andrew. (Midland Metallurgical Societies: Iron and Steel Industry, 1936, vol. 9, Jan., pp. 149–151). The author points out that the mechanism of segregation in steel ingots may be accounted for by the production of gas during solidification. He goes on to consider the nature of the non-metallic impurities in steel, the use of aluminium and molybdenum as deoxidisers, and the influence of dissolved gases.

Some Remarks on the Formation of Flakes in Chromium-Nickel-Molybdenum Steels. I. Musatti and A. Reggiori. (Seventh International Congress on Mining, Metallurgy and Applied Geology, Paris, Oct. 20–26, 1935: Revue de Métallurgie, Mémoires, 1935, vol. 32, Nov., pp. 532–552). The authors first demonstrate that the numerous theories which have been advanced to explain the formation of the fissures frequently observed in hot-worked special steels are inadequate to cover the facts completely. They then describe their experiments on the influence of hydrogen on chromium-nickel-molybdenum steels and correlate them with other investigations on the brittleness, temporary or permanent, resulting from pickling or from the absorption of hydrogen at high temperatures. They conclude that hydrogen is the cause of the fissures, and that they form at a temperature below 280° C. Tests on carbon, low chromium-nickel and chromium-nickel-molybdenum steels revealed the differences in the sensitiveness of these materials to the effect of hydrogen.

"Flakes" in Steel Forgings. L. Guillet and M. Ballay. (Seventh International Congress on Mining, Metallurgy and Applied Geology, Paris, Oct. 20–26, 1935: Revue de Métallurgie, Mémoires, 1935, vol. 32, Nov., pp. 522–530). The authors discuss flakes in steel forgings, their characteristics, the cause of them and factors having an influence on their occurrence, and means of avoiding them.

FORGING, STAMPING AND DRAWING

(Continued from p. 59 A)

Practical Aspects of Drop Forging. H. Kaessberg. (Metal Treatment, 1935, vol. 1, Winter issue, pp. 198–201). Notes on some practical aspects of drop-forging are presented. It is shown that precision in the production of these forgings depends on the type of equipment used, the arrangement of the guides, the accuracy of the dies, and the skill of the operator. The tolerances which may be permitted in drop-forging practice are indicated.

Trends in Pressed Metal Production Equipment—Rugged Simplicity Reappearing. E. V. Crane. (Iron Age, 1936, vol. 137, Jan. 2, pp. 327–340). An outline of the present trend of design in American pressing practice is presented. The present state of development of heavy mechanical presses, hydraulic presses, inclinable and automatic presses is reviewed.

Flat Rolled Steel Products, Processing for Automobile Industry. R. J. Wear. (Iron and Steel Engineer, 1935, vol. 12, Dec., pp. 12–15). The author describes the Budd-McKay processing machine which is designed to eliminate stretcher strains in thin sheets.

The Deep Drawing of Sheet Metal. J. D. Jevons. (Metal Industry, 1936, vol. 48, Jan. 17, pp. 67–72). A number of the practical aspects of the deep-drawing process are touched on; these include: The need for correlating theory and practice, the importance of crystal size and of the general quality of the metal, and the elimination of defects arising from the drawing practice or inherent in the material.

Layout and Maintenance of Wire Working Plant. F. Whitelegg. (Wire Industry, 1935, vol. 2, Dec., pp. 417, 450). Brief notes on lighting, heating, and other factors influencing the well-being, and hence the output, of the operatives are presented.

The Latest 15–21 Die Robertson Wire Drawing Machine. (Wire Industry, 1935, vol. 2, Dec., pp. 447–448). This machine is designed to draw wire from a maximum gauge of 12 S.W.G. through 17, 19, or 21 dies. Its capacity is from 15 to 100 lb.; the finishing speed is 5000 ft. per min., but lower speeds may be obtained through a gearbox, if required. The drive is by a clutch from an electric motor, and is stated to give very flexible control. Special features include the "Figure Eight" threading system, in which there are no idle cones. The die boxes are supported on a tube and are given a reciprocating motion of constant velocity. The dies are lubricated by force-feed from an electric pump fed by a large liquor tank of 70-gal. capacity.

Recent Progress in the Wire Drawing Industry. E. L. Francis. (Metal Industry, 1935, vol. 48, Jan. 17, pp. 78–80). An account of recent developments in wire-drawing practice is presented.

ROLLING-MILL PRACTICE

(Continued from pp. 60 A–62 A)

Rehabilitation and Modernisation in the Iron and Steel Industry during 1935. (Iron and Steel Engineer, 1936, vol. 13, Jan., pp. 28–39). Data concerning the electrical and mechanical characteristics of new American rolling mills put down during 1935, or to be completed at a future date, are set forth.

Progress in the Knowledge and Operation of Processes of Plastic Deformation. E. Siebel. (Metallwirtschaft, 1936, vol. 15, Jan. 31, pp. 103–107). The continuation of a previous article (*see* p. 59 A). In this instalment the author discusses the phenomena taking place during the plastic deformation of materials by rolling.

Lubricant Specifications. O. L. Maag. (Iron and Steel Engineer, 1936, vol. 13, Jan., pp. 13–22). The tests to be applied to lubricants for service in steelworks and rolling mills are briefly outlined, and the types of lubricant suitable for various applications are indicated.

Selection of Lubricants for Cold Rolling of Strip Steel. R. W. Moore. (Iron and Steel Engineer, 1935, vol. 12, Dec., pp. 24–28). The lubricants discussed in this paper are those used (in connection with the rolling of steel strip in the finishing mills) for the purpose of minimising the friction between the rolls and the stock, and to prevent scratching and the effect of atmospheric or other corrosion. After dealing with the salient characteristics of vegetable, mineral, and compounded oils, and of oil emulsions, the author examines the chief factors which govern the selection of roll oil; these are the film strength, thermal properties, ease of cleaning and application, tendency to carbonise or form slush, adhesiveness, covering power and economy. Finally, the application of roll oils to different types of mill is considered.

Enlargement of a Rolling Mill for Sections and Sheet Bars. (Demag News, 1935, vol. 9, Nov., pp. 42–46). With a view to modernising the works and securing a higher output, the sheet bar mill of the Terni Steelworks was reconstructed. The three-high roughing mill and three-high finishing mill already in existence were retained. The motor driving these units was used to drive a new three-high blooming mill, and the old mills were equipped with a new motor. The new stand of rolls is provided with a fixed bottom roll, a moving middle roll, counterbalanced with the tables, and an adjustable top roll; it is so arranged that by changing the rolls and removing the middle coupling spindle it may be converted into a Lauth three-high plate mill. The new mill is furnished with electrically operated tilting tables, and a manipulator, hydraulic shears, and skids for transferring the billets to the finishing section.

Universal Plates for Fabricating Steelwork. (Engineering, 1936, vol. 141, Jan. 3, pp. 10–11). An account of the production and application of the universal plates rolled at the Redcar Works of Messrs. Dorman Long and Co., Middlesbrough, is presented. The plates are rolled in a universal mill comprising a pair of horizontal rolls and two pairs of vertical rolls. All the rolls are driven and all are adjustable. On entering the mill the slabs are reduced by the first pair of vertical rolls and the following horizontal rolls, the far vertical rolls being retracted. On the return pass the far vertical rolls come into operation, the near pair being withdrawn. In this way the plate is rolled on all four surfaces. The mill is capable of producing long plates from 12 to 45 in. wide and from $\frac{1}{4}$ to 3 in. in thickness. While still hot the plate is transferred to a flattening machine, and then passed to a long clamp which holds it straight while it cools. Should any side camber develop it is removed by means of "nipping" rolls; by introducing a thin metal shim between the plate and the rolls excess pressure is developed at the required points, and the curvature is neutralised. The same method is used to put curvature on a universal plate to be used as the web of a cambered girder. Universal plates enable one thick plate to be adopted where several thin plates would ordinarily be specified. Such plates also eliminate the cost of edge planing and reduce drilling and riveting costs. In riveted structures, however, the design of the girders should be suitably modified to allow for the small variations in width which occur. Universal plates are particularly applicable to welded constructions.

Continuous Sheet Mills—What they mean to Costs and Competition. T. H. Gerken. (Iron Age, 1936, vol. 137, Jan. 2, pp. 82–89). The present and projected yearly capacity of continuous sheet and wide strip mills in America is in excess of eight million gross tons. If this capacity is to be fully utilised and the high cost of the plants recouped, outlets for this tonnage must be found in new and existing markets. The author explains how this may be accomplished. He points out that the demand for wide strip and sheet is likely to expand, and that the continuous mills may also be readily adapted to the production of thin plate, merchant strip and tinplate strip. A considerable part of the existing sheet and tinplate capacity is likely to become obsolete, but small mills of the Steckel or similar type will continue to be used for miscellaneous orders. Four-high mills will probably replace two- and three-high units to an increasing extent, and the continuous process will be applied more frequently in the cold-rolling departments.

Developments in Rolling Flat Steel Products during 1935. S. Badlam. (Iron and Steel Engineer, 1935, vol. 12, Dec., pp. 40–50). The principal advances in the rolling of steel sheet and strip which took place during 1935 are outlined. The details of the mills described mainly refer to American practice.

Consumer Requirements now Dictate Mill Equipment. T. W. Lippert. (Iron Age, 1936, vol. 137, Jan. 2, pp. 430–445). A review of some of the chief developments in American steel-mill practice is presented. Among the matters touched on are the following: The progress of the continuous mill, and of other types of strip mill; developments in cold-rolling practice, including cluster and ring mills; the adoption of antifriction bearings; the cold-forming of shapes in alloy steel strip; the production of strip by slitting continuous sheet; and the advances in annealing and sorting equipment.

Roll-Table Equipment for Modern Wide Strip Mills. G. A. Caldwell and S. F. Henderson. (Iron and Steel Engineer, 1935, vol. 12, Dec., pp. 29–38). The authors deal chiefly with the electrical and mechanical characteristics of the motors used for table-roll drives in wide strip mills.

Flat Rolling of Steel. Factors Influencing its Production. C. L. McGranaham. (Iron and Steel Engineer, 1935, vol. 12, Dec., pp. 1–8). The author discusses the principal factors which determine the production and quality of flat-rolled strip; the matters touched on include the selection and treatment of the slabs, the operation of the roughing and finishing trains, the drafts used, the camber of the rolls, the method of coiling, and the operation of the shears.

Design and Construction of the Ford Steel Mill. M. Stone and C. F. Buente. (Blast Furnace and Steel Plant, 1935, vol. 23, Dec., pp. 833–839). (*See* p. 61 A).

Carnegie-Illinois 43-in. Strip Mill. (Blast Furnace and Steel Plant, 1935, vol. 23, Dec., pp. 867–869). (*See* p. 62 A).

Strip Mill for Wide Strips. (Demag News, 1935, vol. 9, Nov., pp. 38–41). In order to cope with the demand for wider strip, and to increase the output of the mill, the strip mill at Dinslaken was reconstructed. The new equipment which was installed is described. This included the provision of two new slab-heating furnaces in place of the one previously used, and a special slab conveyor, alterations to the edging stands (to accommodate the wider material) and an increase in the motor power of the plant.

Continuous Wide Strip Mill Now Being Built in Russia. M. Stone. (Steel, 1935, vol. 97, Dec. 9, pp. 32–35, 57). Particulars of a modern steel mill in course of construction at Zaporojie, U.S.S.R., are presented. The completed mill will house a 66-in. (1680-mm.) continuous hot strip mill, several cold mills, and the necessary finishing departments. Slabs are heated in three 50-ton gas-fired furnaces; they pass to a two-high scale breaker (710 × 1680-mm. rolls) succeeded by a four-high roughing stand with rolls 914 and 1320 × 2438 mm., provided with a turntable for lengthwise rolling of the slabs. The remainder of the roughing train comprises three units of four-high mills, with 610 and 1240 × 1680-mm. rolls, each preceded by motor-driven edgers. The roughing and finishing

trains are separated by a cooling table equipped with a special high-velocity air-blast system. After passing through a flying crop shear the hot strip enters the finishing train, comprising a two-high 610 × 1680-mm. scale breaker, followed by six stands of four-high finishing mills with 610 and 1240 × 1680-mm. rolls. Hot coiling is accomplished by three hot reels at the far end of a hot table 120 m. long. Special features of the mill are the centralised system of lubrication, the attention paid to scale removal, the rapidity with which rolls may be changed, and the wide adoption of ball and roller bearings. Two cold-run tables are each 275 m. long and are capable of dealing with the full capacity of the mill. The equipment in the hot-finishing department enables the material to be open-annealed, pickled, and skin-passed, or, alternatively, it may be skin-passed without pickling, or pickled and skin-passed without annealing. The skin-pass mills comprise two four-high units with 420 and 1210 × 1680-mm. rolls. The cold mill includes three stands of four-high mills, with rolls 1680 mm. wide, followed by two four-high reversing mills with rolls 485 and 1370 × 1680-mm. and 405 and 1240 × 1060-mm. On leaving the cold-rolling mills the strip is annealed in box-annealing furnaces, and pickled, scrubbed, and dried. The finishing (planishing) department consists of seven planishing and tempering mills, including two four-high planishers, four two-high units, and one four-high coil planisher. Comprehensive auxiliary equipment is being installed. The whole plant is designed to have a capacity of 300,000 metric tons of finished sheets a year.

Notes on Cold Rolling. J. W. Berry. (Staffordshire Iron and Steel Institute, Oct. 29, 1935 : Iron and Coal Trades Review, 1935, vol. 131, Nov. 8, pp. 759–760). After briefly touching on the early history of the cold-rolling process—a process which appears to have been introduced into Germany by Friedrich Krupp in 1837, and in England by Samuel Fox some years later—the author comments on some of the aspects of present-day practice. He remarks that pickling is now receiving greater attention than has hitherto been the case—a step long overdue. He summarises the comparative advantages and disadvantages of two-high, four-high, and cluster mills, and concludes with short notes on annealing, and blue-brittleness and stretcher strains.

The Manufacture of Seamless Tubing. A. B. Graham. (Metal Industry, 1936, vol. 54, Jan. 17, pp. 81–86). An account of the more recent advances in the production of seamless tubes—including hot-working, cold-working and extrusion processes, and annealing practice—is presented.

Manufacture of Steel Tubes. J. W. Jenkin. (Midland Metallurgical Societies, Jan. 2, 1936 : Iron and Coal Trades Review, 1936, vol. 132, Jan. 10, p. 45). A brief outline of the factors which affect tube-manufacturing processes—such as the effect of inclusions, the method of forming, and the structure of the steel—is presented.

HEAT TREATMENT

(Continued from pp. 63 A–72 A)

Soft Spots on Hardened Steel. H. H. Bleakney. (Iron Age, 1935, vol. 136, Dec. 12, pp. 32–33, 94, 96). On the basis of some early work by Ehn and McQuaid on carburising, and of later work by other investigators on the hardening and quenching of steels, the author discusses the formation of soft spots in hardened steel. He remarks that successful hardening depends on two factors: The quenching conditions, and the quality of the steel. He suggests that the presence of non-metallic inclusions, or of carbide particles, may give rise to an increase in the critical hardening velocity, and hence to the formation of soft spots when normal hardening speeds are used. The remedy is to avoid "dirty" steel and the presence—as far as possible—of hypereutectoid carbide in case-hardened steel.

Surface Hardening by Local Heat Treatment. A. Matting. (Maschinenbau, Oct., 1935: Metal Treatment, 1935, vol. 1, Winter issue, p. 205). Notes on the flame-hardening process are presented.

The Scaling of Iron and Steel. (Metallurgist, 1935, Dec. 27, pp. 82–85). A brief outline of the research work which has been carried by various investigators on the scaling of iron and steel is presented; the evidence which has been advanced with regard to the mechanism of scaling, the scaling of alloy steels, and the formation of scale in furnace and other complex atmospheres is critically discussed.

Controlled Atmospheres in Steel Treating. H. W. Gillett. (Metals and Alloys, 1935, vol. 6, Aug., pp. 195–203; Sept., pp. 235–246; Oct., pp. 293–298; Nov., pp. 323–327). The author points out that both oxidation and decarburisation during heat treatment are undesirable, and that by adopting a suitable furnace atmosphere these effects may be eliminated. A section is devoted to the action of the usable gases, and their cost, and this is followed by a description of the types of furnace to which controlled atmospheres may be applied. Scaling and decarburisation, particularly the behaviour of high-speed steel, and spring steel and carbon steel, are treated in some detail. The author goes on to discuss the bright annealing of steel strip and sheet material, the use of gas in carburising practice (and particularly the behaviour of town gas) and the types of carburising furnace employed. Finally, the main points which arise when controlled atmospheres are adopted in heat-treating, finishing or processing applications are summarised.

The Heat Treatment of Cast Iron. A. A. Timmins. (Proceedings of the Staffordshire Iron and Steel Institute, 1934–35, vol. 50, pp. 121–128).

Heat Treating 1000 Different Parts. J. B. Nealey. (Steel, 1935, vol. 97, Dec. 23, pp. 24–26). The heat-treating department of the International Business Machines Corp. is described. In order to simplify treatment of the many parts handled, the number of steels used has been reduced to five, although other steels are used for special applications. Gas-fired box-type furnaces are installed in the annealing and carburising sections; they are fully equipped with automatic temperature control. For the cyanide hardening adopted for certain parts pot furnaces are in use.

Thermal Treatment of Alloy Tool Steels. R. Saxton. (Heat Treating and Forging, 1935, vol. 21, Nov., pp. 515–516, 521). Notes on the heat treatment of alloy steels are furnished.

Continuous Mechanical Furnaces. J. Fallon. (Staffordshire Iron and Steel Institute, Dec. 10, 1935: Iron and Coal Trades Review, 1935, vol. 131, Dec. 20, pp. 1024–1025). After referring to the principal features of batch furnaces for the annealing of steel sheets and the preheating of bars, the author describes the chief types of continuous furnace now being used, their special features, and the service which they may be expected to give.

Bright Annealing. (Wire Industry, 1935, vol. 2, Dec., pp. 427–428). Practical details of the procedure to be followed in the bright-annealing of wire are furnished.

The Effect of Annealing on the Release of Internal Stress in Cold-Drawn Rods. K. Saito. (Kinzoku No Kenkyu, 1935, vol. 12, Dec. 20, pp. 551–559). The effects of annealing on the release of internal stress and the hardness change in cold-drawn rods were studied. Seven metals, including Armco iron and steels containing 0·3, 0·8, and 1·3% of carbon, were investigated. The release of internal stress was inferred from the change in the length of the rod (measured in the direction of drawing) at room temperature, to which the specimen was cooled down slowly after being annealed at different temperatures for half an hour; the annealing was repeated at successively higher temperatures. In the case of iron and steel, the rod was found to elongate and then contract. The temperature at which the internal stress was released was about 650°, and the increased hardness due to cold-working was reduced to its original value in the vicinity of this temperature.

Heat Treatment of High-Speed Steels. I. Feszczenko-Czopiwski and A. Ascik. (Państwowe Wytwórnie Uzbrojenia, Prace Badawcze, 1935, No. 4, pp. 47–146). Tungsten is one of the most important alloying elements in high-speed steels. It controls the brittleness (grain-size), melting point, quenching temperature, the degree and stability of the secondary hardness, and the content of austenite after quenching and tempering. The value of tools made of high-speed steel depends very much on all the details of the heat treatment to which they have been submitted; a very high hardness after quenching coupled with long tool life have been obtained by quenching in a lead bath held at a temperature of about 430° C.

Measurements of the austenite content in relation to the mode of heat treatment, the dilatometric curve of high-speed steel up to 1300°, and observations of the structural changes due to the effect of temperature and the mode of quenching appear to indicate that high-speed steel undergoes a γ–δ transformation at about 1150°, and that, therefore, the region of the γ phase does not extend up to the temperatures of practical quenching. The δ phase—in which carbides are soluble, to an extent varying with the temperature—transforms on quenching into the α phase; this occurs by a simple reduction of the lattice parameter, without the δ–γ transformation taking place. The solubility of carbides in this α phase is extremely low. The austenite, which can be observed in the quenched samples, forms during the quenching from those parts of the δ phase which had not transformed to α phase, this owing to the rapid cooling, which lowers the temperature limit of the γ phase to room temperature. The more violent the quenching the less is the amount of austenite formed. The secondary hardness is influenced to a certain extent by the allotropic transformation—the decomposition of austenite—which is most intense between 500° and 600° C., the range within which this hardness is developed. This transformation favours secondary hardening; during the γ–α transformation, the foreign atoms are expelled from the lattice; they form intermetallic compounds; and, as the conditions are probably favourable, they grow to the critical size and harden the alloy. As a result of the transformation no temper martensite forms, but probably troostite; the corrodibility of high-speed steel seems to point to this. The boundaries of the grains seen on the polished surface of the quenched metal are not those of austenite but of original α grains. The homogenisation of the steel in the normal manner, more easy and rapid as the temperature is raised, becomes less intense in the neighbourhood of the melting point; an inverse reaction then sets in, namely, a differentiation of the concentration of the elements, which lowers the melting point in the separate grains, that is, intracrystalline segregation.

Steels for the User—XIV. Heat Treatment of Steel. R. T. Rolfe. (Iron and Steel Industry, 1935, vol. 9, Dec., pp. 117–120). An outline of the formation and characteristics of the constituents of carbon tool steel is presented. The effect of quenching and tempering a carbon steel of eutectoid composition—particularly the effect on the hardness and impact value—is examined in some detail.

Treatment of Steel for Clock and Gramophone Mainsprings. F. L. Tingle. (Sheffield Trades Technical Societies: Iron and Steel Industry, 1935, vol. 9, Dec., pp. 121–124). The heat treatment of carbon steel mainsprings is discussed. It is pointed out that in view of the low inherent ductility of the hardened material it is essential to avoid structures which are themselves brittle. Thus, the steel should be hardened from a temperature of 760–780° C.,

just above the Ac_1 point, for the martensite is then in the finely crystalline state; too high a temperature promotes the formation of coarse, brittle martensite. It is also essential that the material should be in the correct condition prior to heat treatment; cold-rolling, and intermediate annealing at successively lower temperatures, from 760° to 660° C., is recommended. The cementite is then in the spheroidised, finely divided state; if the annealing temperature is too high it will be coarse, and difficultly soluble on heat treatment. Inclusions, and a decarburised skin, should also be avoided.

On the Quenching of Steels and its Mechanism. K. Honda. (Science Reports of Tôhoku Imperial University, 1935, vol. 24, Nov., pp. 551–564). The author discusses the transformations which take place when iron and steel are quenched or tempered, with particular reference to the martensite transformation. He recapitulates the main points concerning the phase changes which occur when a carbon steel is quenched and tempered, and accounts for the formation of the constituents which successively appear. He then shows that two types of martensite may be distinguished: the first, α-martensite, is that which forms on quenching; the second, β-martensite, is the modification produced by tempering α-martensite for a short time at about 80–100° C. He produces evidence to demonstrate that martensite is better regarded as a solid solution of carbon in ferrite, rather than a mixture of cementite and ferrite, and, on the basis of X-ray investigations of the crystal structure, explains the mechanism of the formation of the two varieties of martensite.

An Examination of Some Quenching Liquids. N. E. Wood. (Journal of the Institution of Petroleum Technologists, 1935, vol. 21, Dec., pp. 995–998). The author describes some results of quenching experiments in which different oils were used as the quenching media in standardised quenching tests. In these tests a standard steel specimen was heated to 850° and plunged into the cooling medium; cooling curves for the various media were constructed. Figures showing the effect of bath temperature on the rate of cooling are also given. In this connection the author observes that, within limits, the decrease in the viscosity of the oil at higher temperatures more than counteracts the retarding action of a higher bath temperature.

WELDING AND CUTTING

(Continued from pp. 73 A–80 A)

Outline of the Welding and Oxy-Cutting Industry in the United States. L. de Jessey. (Bulletin de la Société des Ingénieurs Soudeurs, 1935, vol. 6, Nov.–Dec., pp. 1990–2005).

Modern Methods of Welding. C. H. Davy. (Institution of Chemical Engineers, Oct. 9, 1935 : Journal of the Society of Chemical Industry, 1935, vol. 54, Dec. 6, pp. 1054–1057). The author classifies and describes modern welding methods under the following main headings : Forge and hammer welding; acetylene welding; electric resistance butt welding; the atomic hydrogen process; and metallic-arc fusion welding. The results obtainable by each method are briefly outlined, and the respective fields of application are indicated.

Some Characteristics of the Welding Flux Affecting the Welding Arc. H. Shibata. (Transactions of the Society of Mechanical Engineers, Japan, 1935, vol. 1, Aug., pp. s-72–s-73). An investigation of the effects of welding fluxes on the characteristics of the arc is reported. Thirty different fluxes were experimented with, and the melting times and arc voltages were determined. It was observed that when a single metallic compound was used as a flux the arc voltage decreased and the melting time increased as the atomic weight of the metallic element in the flux decreased; this is explicable on the basis of the electron affinity of the oxide of the metal concerned. The melting time of the welding rod was found to be dependent on the arc voltage so long as the current and other conditions were constant; the curve relating melting time and arc voltage is a rectangular hyperbola, but with a low arc voltage a short-circuit frequently occurs, and this makes the actual melting time apparently far greater than the theoretical value. With most of the fluxes investigated the arc voltage was observed to vary with the polarity of the electrodes; but not all the fluxes behaved in the same way. Bare welding rods of different chemical composition gave different arc voltages and melting times, even when the current conditions were the same; but when coated with the same kind of flux the melting times and arc voltages were seen to be peculiar to the flux, and independent of the type of core. Hence the inherent nature of the flux may be regarded as the most important factor governing the welding arc characteristic.

British Standard Specification for Rating of Electric Arc Welding Plant and Equipment and for Welding Accessories. (British Standards Institution, No. 638–1935).

British Standard Specification for Covered Electrodes for Metal Arc Welding Wrought Iron and Mild Steel (For Hand Operation). (British Standards Institution, No. 639–1935).

British Standard Specification for Bare Rod or Wire Electrodes for Metal Arc Welding Wrought Iron and Mild Steel. (British Standards Institution, No. 640–1935).

The Applications of Welding in the Workshops of a Railway Company. A. Heydacker. (Bulletin de la Société des Ingénieurs Soudeurs, 1935, vol. 6, Nov.–Dec., pp. 1960–1978).

Columbium in Welding Rods for Stainless Steels. W. J. Priestley. (International Acetylene Association: Metal Progress, 1935, vol. 28, Dec., pp. 56–58). It is pointed out that the presence of chromium in stainless steel leads to difficulties during welding; in particular, it tends to form chromium carbide, which makes the steel air-hardening and likely to crack. The addition of either columbium or titanium to the welding rod suppresses this tendency, and also improves the ductility of the material. Columbium also is particularly useful in that it inhibits intergranular brittleness in welded 18/8 alloys.

Analysis of the Circular of July 25, 1935 (Specification for the Construction of Frames and Bridges of Steel with Electric-Arc-Welded Assemblies). A. Goelzer. (Bulletin de la Société des Ingénieurs Soudeurs, 1935, vol. 6, Nov.–Dec., pp. 1979–1989). In a letter dated July 25, 1935, the French Minister for Public Works states that the provisional specification for the construction of frames and bridges of steel with electric-arc-welded assemblies, referred to in an earlier letter, dated July 19, 1934, addressed to the Engineers-in-Chief of the Department of Bridges and Highways, shall now no longer be regarded as "provisional," subject to the incorporation of various modifications attached to his letter. The present author gives a rapid survey of the provisions of the specification.

Fatigue Tests on Welded and Brazed Assemblies. Miss L. Doussin. (Bulletin de la Société des Ingénieurs Soudeurs, 1935, vol. 6, Nov.–Dec., pp. 1939–1959). The results of fatigue tests (rotating four-point suspension and cantilever type) on specimens consisting of a tube and sleeve fastened together by welding, brazing, hard soldering, and soft soldering, are presented and discussed. A chromium-molybdenum steel and a low-carbon steel were included in the tests.

Considerations on the Fatigue Resistance of Welded Structures. H. Dustin. (Revue Universelle des Mines, 1935, vol. 11, Dec., pp. 521–531). The author first reviews the fatigue resistance of materials in general and its definition, the endurance limits of weld metal and the distribution of the stresses in welded joints. He emphasises the need for direct experimentation on welded assemblies, and then describes briefly certain testing machines and discusses the results of several recent important researches. The endurance limits of the various types of welded joints differ considerably; the butt-weld is much superior to the fillet welds. Welded joints which have been correctly designed with regard to

static loads break by fatigue outside the weld; their endurance is practically independent of the strength of the filler metal and is controlled essentially by discontinuities of shape and by the resulting sharp inflexions of the lines of stress. Special structural steels of high strength are more sensitive to these influences than mild steel.

Bend Testing of Welds—A Summary. M. F. Sayre. (Journal of the American Welding Society, 1935, vol. 14, Dec., pp. 2–10). This article represents a partial report on an investigation of methods of testing welds. The present study deals with bend tests; the information which is summarised is drawn from both European and American sources.

Recent Research on the Physical and Mechanical Properties of Electric Weld Metal. J. H. Paterson. (Institute of Welding, Oct. 15, 1935: Welding Industry, 1935, vol. 3, Nov., pp. 366–370). This paper mainly consists of a critical review of the papers dealing with the mechanical and physical properties of electric weld metal which were contributed to the Welding Symposium of the Iron and Steel Institute.

Study of the Mechanical Properties of Welds by Means of the Micromachine. P. Chevenard. (Bulletin de la Société des Ingénieurs Soudeurs, 1935, vol. 6, May–July, pp. 1760–1772). (*See* Journ. I. and S.I., 1935, No. I., p. 428).

PROPERTIES AND TESTS

(Continued from pp. 82 A–104 A)

The Effect of Cold Bending on the Elastic Properties of Heavy (3½ in. thick) Steel Plates. C. H. Gibbons. (Proceedings of the American Society for Testing Materials, 1935, vol. 35, Part II., pp. 275–282). The author reports the results of a series of experiments in which test specimens were taken from various parts of the plate both in the cold-bent condition and in the stress-relieved condition, and stress-strain determinations were made on each specimen. No conclusions are drawn, as the paper is intended only as a presentation of little-known data on a complex and controversial subject.

Notched Bar Impact Tests. G. Burns. (Metallurgist, 1935, Dec. 27, pp. 86–88). An account of some results obtained from a series of tests on notched-bar specimens of different shapes and forms is presented. The author compares the impact figures obtained from standard (10 × 10 mm.) and sub-standard (10 × 5-mm., and 5 × 5-mm.) specimens, using samples of nickel and nickel-chromium-molybdenum steels. He points out that although the results obtained from each size of test-piece were consistent among themselves, the ratios of the values given by the standard and sub-standard specimens fluctuated widely; hence any attempt to convert figures obtained on smaller test-pieces into the standard impact figure is subject to the possibility of a large error. The author goes on to compare the results obtained from tests on the British standard 10 × 10-mm. specimen and the German test-piece of the same dimensions (but with a different notch, however). He discusses the effect of increasing the notch depth (which is 3 mm. in the German specimen, compared with 2 mm. in the British specimen) and of increasing the radius of the notch. He observes that with a fixed total depth of specimen, *viz.*, 10 mm., the impact figure tends to be proportional to the depth below the notch in brittle materials, and to the square of the depth in tough materials. Tests on the British and German specimens gave ratios varying between 0·8 and 1·3 for nickel-chromium-molybdenum steels, and 1·1 and 1·5 for nickel steels; the figures were somewhat scattered, but they appear to lie about the values of 1·1 and 1·2 respectively.

The Distortion of β-Brass and Iron Crystals. C. F. Elam. (Proceedings of the Royal Society, 1936, Series A, No. 879, vol. 153, pp. 273–301). Some further experiments on the distortion in tension of the body-centred cubic metals, iron and β-brass, are described and the conclusion is arrived at that there is no essential difference between them. Although slip-bands agreeing with possible crystal planes—chiefly [110] planes, less frequently [112]

planes—are usual, calculations of the distortion do not agree with slip on these planes throughout the extension. Moreover, the direction of slip is not always a [111] direction, although this is the most common direction found. It is suggested that the deformation does not take place by slip on any definite crystal plane, but that the distortion is brought about by movements of a complicated nature originally related to the structure, but finally having no obvious connection with it. The fact that the distortion cone usually consists of two planes limits the possibilities, but no definite conclusion has been arrived at as to the details of the distortion. Stress-strain curves of the crystals are given and the fracture of β-brass crystals in tension and in rolling are described.

A New Photoelastic Material. A. G. Solakian. (Mechanical Engineering, 1935, vol. 57, Dec., pp. 767–771). Marblette is a transparent phenolic material suitable for the construction of stress models for examination under polarised light. The material is stated to possess a high stress-optical coefficient and good machining properties; it is easy to cast into intricate shapes and is free from initial stresses. The author compares the photoelastic properties of marblette with those of the other materials (glass, bakelite, celluloid, &c.) used for stress analysis.

Intercrystalline Failure of Metals. J. C. Chaston. (Metals Treatment, 1935, vol. 1, Winter issue, pp. 186–190). The author, after commenting on the general aspects of intercrystalline failure, classifies the types of failure under the following headings: (*a*) Failure of weak intercrystalline constituents under stress; (*b*) total failure of the boundary cement under stress at temperatures near the melting point; (*c*) failure of the boundary cement under creep at temperatures in the recrystallisation range; (*d*) selective corrosion of boundary cement in unstressed metal; (*e*) intercrystalline corrosion by specific agents acting only when the metal is stressed; (*f*) failures possibly involving stress concentration at the crystal boundaries. Each type of failure is discussed in turn, with illustrative examples.

Fatigue of Metals. H. J. Gough. (Proceedings of the Staffordshire Iron and Steel Institute, 1934–35, vol. 50, pp. 74–97). The author discusses fatigue testing machines, corrosion-fatigue, fatigue testing of full-sized components, fatigue tests at low temperatures, and the Moore and Wishart method of determining the fatigue limit.

Frictional Oxidation at Fixed Joints and its Importance in Regard to Fatigue Failure. A. Thum and F. Wunderlich. (Zeitschrift für Metallkunde, 1935, vol. 27, Dec., pp. 277–280). Frictional oxidation at a fixed joint between two machine parts is the result of the joint action of mechanical fatigue and oxidation; the former is the primary factor, because wear occurs on the seatings —though only to a slight extent—even in the absence of oxygen. The reduction of the fatigue strength by the action of the stresses

set up in fitting the parts together (for instance, a wheel on its axle) must be ascribed primarily to the peculiarity of the deformation process during the alternating stressing. Oxidation, as the secondary factor, acts as a promoter. Further observations suggest that frictional oxidation occurs at fixed joints even under the lowest stresses, but the measurement of the latter does not give immediately any indication of the danger of fatigue failure. From the asymptotic shape of the Wöhler curves it is concluded that there is a definite value for the " seating fatigue strength " (*Einspanndauerfestigkeit*).

Determination of Magnetic Hysteresis with the Fahy Simplex Permeameter. R. L. Sanford and E. G. Bennett. (National Bureau of Standards Journal of Research, 1935, vol. 15, Nov., pp. 517–522). An attachment for the Fahy Simplex permeameter is described by which the *H*-coil can be rotated end for end. By means of this attachment, values of the magnetising force *H*, corresponding to points on a hysteresis loop, can be attained with high precision. Smoother curves are obtained in less time than can be done with the original arrangement.

Magnetic Alloys of Iron, Nickel and Cobalt. G. W. Elmen. (Electrical Engineering, 1935, vol. 54, Dec., pp. 1292–1299). An account of the magnetic properties, heat treatment and application of the ferromagnetic alloys of iron, nickel, and cobalt (permalloy, perminvar, and permendur), is given.

Contributions to the Data on Theoretical Metallurgy. III. The Free Energies of Vaporisation and Vapour Pressures of Inorganic Substances. K. K. Kelley. (United States Bureau of Mines, 1935, Bulletin No. 3831). The work described is a continuation of that reported in two earlier publications (Bulletins Nos. 350 and 371) which dealt with the entropies at 298·1° K. and the specific heats at high temperatures of inorganic substances. In the present work the entropy values and specific-heat equations are applied to vapour pressure and other pertinent data in obtaining heat and free energy of vaporisation equations for inorganic substances valid up to the normal boiling or sublimation points (760 mm. pressure). Tables showing the vapour pressures for inorganic substances at various temperatures up to and including the boiling or sublimation point are given. A bibliography of literature on vapour-pressure data is also appended.

The Vapour Pressures of Metals. A. Eucken. (Metallwirtschaft, 1936, vol. 15, Jan. 10, pp. 27–32; Jan. 17, pp. 63–68). The author presents a critical survey of the results of the researches of numerous investigators; several metals of interest to the ferrous metallurgist are included, and brief reference is made to iron. Fifty-four references to the literature on the vapour pressures of metals are given.

Creep in Relation to Design. (Metal Treatment, 1935, vol. 1, Winter issue, pp. 202–204, 209). This is an abridged English trans-

lation of an article by Rudorff which appeared in Zeitschrift des Vereines deutscher Ingenieure, 1935, vol. 79, Apr. 13, pp. 453–458. (*See* Journ. I. and S.I., 1935, No. I., p. 477).

Gases in Steel. T. Swinden. (Newport and District Metallurgical Society, Nov. 9, 1935: Iron and Steel Industry, 1935, vol. 9, Dec., pp. 100–106). This paper is an account of the occurrence, estimation, and effect of gases in steel, based largely on the work of the Committee on the Heterogeneity of Steel Ingots and of certain other investigators in the same field. The author describes the form in which oxygen is present in steel, and the method of estimating and controlling it, and in this connection discusses the behaviour of rimming steel. He continues by explaining the results obtained by passing various gases through liquid steel. Brinell's work on the production of sound steel is examined; other matters touched on are the jarring of ingots, and the occurrence of carbon monoxide and nitrogen in liquid steel.

Gases in Metals. C. J. Smithells. (Metal Treatment, 1935, vol. 1, Winter issue, pp. 165–171). The author attempts to summarise the data relating to the adsorption, diffusion and solution of gases in metals. He gives a brief account of some of the phenomena associated with diffusion and adsorption, and of the theoretical aspects of these processes; he shows that solubility is related to adsorption and diffusion, and, indeed, depends on them.

Hydrogen Permeability of Copper, Iron, Nickel, Aluminium and Some Alloys. W. Baukloh and H. Kayser. (Zeitschrift für Metallkunde, 1935, vol. 27, Dec., pp. 281–285). The authors have made tests on the hydrogen permeability at various high temperatures on series of alloys, including iron-nickel alloys and Armco iron. In the alloy series only qualitative connection between the permeability and the alloy content was found. Armco iron gave erratic results at the α–γ transformation.

Influence of the Ordinary Alloying Elements on the Properties of Steel. E. C. Bain. (Seventh International Congress on Mining, Metallurgy and Applied Geology, Paris, Oct. 20–26, 1935: Revue de Métallurgie, Mémoires, 1935, vol. 32, Nov., pp. 553–561). The author discusses the effects of the addition of small quantities of alloying elements (not more than, say, 5%) to steel (with at least 0·3% of carbon; with this content the steel is decidedly heat-treatable, and the alloy additions are more effective in these steels); in particular, he deals with the rate of transformation and quenchability, the grain-size and its influence on the quenchability and the mechanical strength, the increase of strength due to elements dissolved in the ferrite, and the characteristics of the carbides containing alloying elements.

Phosphorus as an Alloying Element in Steel. H. W. Gillett. (Metals and Alloys, 1935, vol. 6, Oct., pp. 280–283; Nov., pp. 307–310). The author points out that although phosphorus is

usually regarded as an injurious constituent in steels, it may in fact be usefully employed as an alloying element if only the carbon content is not too high. He adduces evidence from various investigators to show that within certain limits of phosphorus and carbon contents the former element may be used to improve the strength, yield point, hardness, and machinability, without seriously reducing the impact strength or workability. When added to certain corrosion-resistant steels—copper-bearing steels, for instance—phosphorus has a markedly beneficial effect. The author goes on to examine the effect of phosphorus on the impact properties of steel, and the related effects of temperature of testing and of grain-size; attention is then devoted to the problem of segregation. Finally, the alloy systems in which phosphorus appears as an alloying element receive treatment. It is shown that at a certain high phosphorus content, which varies according to the composition of the steel (especially the carbon content), the impact resistance drops; the drop is very marked at sub-normal temperatures. The fall in impact resistance sets in at phosphorus contents below those at which the ductility or workability are seriously affected. The impact properties should be capable of improvement by grain-size control and the addition of alloying elements.

Recent Applications of Molybdenum in Siderurgy. J. Cournot. (Seventh International Congress on Mining, Metallurgy and Applied Geology, Paris, Oct. 20–26, 1935 : Revue de Métallurgie, Mémoires, 1935, vol. 32, Nov., pp. 562–576). A general survey of the use of molybdenum as an alloying constituent in rolled and forged steels, cast steels and cast irons, and its influence on the properties of the materials.

The Importance of Aluminium Additions in Modern Commercial Steels. H. M. McQuaid. (Transactions of the American Society for Metals, 1935, vol. 23, Dec., pp. 797–838). (*See* Journ. I. and S.I., 1935, No. II., p. 493).

Grey Cast Iron. J. W. Bolton. (Foundry, 1935, vol. 63, Oct., pp. 36–37, 78; Nov., pp. 36–37, 81, 82; Dec., pp. 36–37, 80–84). The continuation of a series of articles describing the metallurgical and metallographic characteristics of grey cast iron. The present instalments deal with the effects of sulphur, nickel and chromium on the structure and properties. (*See* Journ. I. and S.I., 1935, No. II., p. 460).

Hardening Cast Iron with Alloy Additions. J. S. Vanick. (Metal Progress, 1935, vol. 28, Dec., pp. 42–47, 80). It is pointed out that cast iron may be hardened without resorting to chills if the silicon content is reduced in order to diminish the amount of free carbon, and if in addition suitable alloying elements are added—such as nickel and chromium. Quite small percentages of these two metals impart considerable hardness to the iron without impairing the machinability. Examples of the application of these hard cast irons are given.

Heat-Resisting Cast Irons in the Construction of Heat Exchangers. Le Thomas. (Chaleur et Industrie, 1935, vol. 16, Dec., pp. 533–536). The author discusses the properties of cast irons from the point of view of their use in the construction of heat exchangers. For temperatures below 400° C., varying slowly, and a feebly oxidising atmosphere, ordinary foundry iron is suitable (it corrodes sensibly less than steel under these conditions); for higher temperatures fine-graphite, so-called pearlitic, iron should be used. For the same conditions, but with temperatures up to, but not exceeding, 800°, an iron with 0·5–0·7% of chromium is recommended; with 1·0–1·5% of chromium and up to 3% the iron will be resistant up to 1000° C., but the castings will be brittle and will not withstand temperature variations. For rapidly varying temperatures, which set up internal stresses that are the more severe when the castings are rigid, 5–7% silicon irons should be used; for corrosive atmospheres the same irons are usable, but when they are excessively corrosive, 30–34% chromium low-carbon irons or nickel-copper-chromium austenitic irons must be employed.

Recent Progress in the Special Steels. Sir Robert Hadfield, Bart. (Seventh International Congress on Mining, Metallurgy and Applied Geology, Paris, Oct. 20–26, 1935: Revue de Métallurgie, Mémoires, 1935, vol. 32, Dec., pp. 591–613). In his introduction, the author first pays homage to French metallurgists, and then touches on the rapid advances made in the special steels, and co-operation in scientific research. Under the general heading of progress in the practical applications of special steels, he discusses the importance of these alloys, heat- and acid-resisting steels, improvements in the ferro-alloys, the development of welding methods, special steel for steam-turbine blades, tool steels, permanent magnet steels, non-magnetic steels, nitriding, manganese and silicon steels and the large economies effected by their use, high-tensile steels and structural steels. The next section deals with progress in scientific metallurgy; the author discusses precipitation hardening, austenitic steels, ferritic steels, gaseous elements in iron alloys, the scope for further researches, the influence of impurities, the co-ordination of present-day knowledge, Faraday's researches on "steel and the alloys," preparation of alloys by sintering, and progress in general knowledge of metallurgy and its influence on the special steels. In conclusion, papers on special steels published by Portevin during the period 1925–1935, and scientific publications of Chevenard during the years 1914–1935 are listed.

Application of Alloy Steels. H. W. McQuaid. (Iron Age, 1935, vol. 136, Dec. 26, pp. 18–22). A general outline of the reasons for using alloy steels in preference to plain carbon steels, and an indication of the relative fields of usefulness of both alloyed and unalloyed steels, is furnished.

Progress in Corrosion- and Heat-Resisting Steels. W. H. Hatfield. (Metallurgia, 1935, vol. 13, Dec., pp. 41–44). The

development, composition, physical and mechanical properties of corrosion- and heat-resisting steels are surveyed.

The Tool Steels. I. Feszczenko-Czopiwski. (Państwowe Wytwórnie Uzbrojenia, Prace Badawcze, 1935, No. 4, pp. 7–43). The simplest classification of tool steels is into carbon steels and special steels. The carbon steels are grouped according to their carbon contents, and their quality is judged by their behaviour on being quenched; this depends on their purity and on the regular carrying-out of the metallurgical processes. In conformity with the classification of the steels according to their carbon contents, the rules for their application have been worked out, and the principles of their thermal treatment have been established according to the most recent researches. With regard to the special steels, the effects of the alloying elements on the properties of the steels and on their response to heat treatment are described; the special tool steels are grouped according to their composition and application. Consideration is also given to the stellites and tool alloys of the Widia and Carbolloy types.

The Development of the Gun Barrel since the 19th Century. F. Dörge. (Zeitschrift des Vereines deutscher Ingenieure, 1935, vol. 79, Nov. 2, pp. 1327–1332). The author touches on the development of gun barrels, modern rifling, erosion, design and methods of manufacture, including centrifugally-cast barrels.

British Standard Specification for the Dimensions of Small Rivets (Ferrous and Non-Ferrous, of Nominal Diameters below $\frac{1}{2}$ in.) for General Purposes. (British Standards Institution, No. 641–1935).

British Standard Specification for Capping Metal for Steel Wire Ropes. (British Standards Institution, No. 643–1935).

METALLOGRAPHY AND CONSTITUTION

(Continued from pp. 105 A–111 A)

The Macroscopic and Microscopic Testing of Metals. P. Regnauld. (Mémorial de l'Artillerie Française, 1935, vol. 14, No. 3, pp. 597–632). After dealing briefly with the work of the Association Française de Normalisation on the standardisation of testing methods for the macro- and micro-examination of steel products, the author describes and illustrates the application of the tests, the features revealed and the conclusions to be drawn from them.

The X-Ray Powder Photography of Alloys. A. J. Bradley. (Midland Metallurgical Societies: Metallurgia, 1935, vol. 13, Dec., pp. 69–70). After briefly indicating the method of obtaining powder photographs in X-ray crystal analysis, the author gives a brief account of some examples of the use of this technique.

On Tetragonal Martensite in Carbon Steels. Z. Nishiyama. (Science Reports of Tôhoku Imperial University, 1935, vol. 24, Nov., pp. 517–522). In order to confirm the view that tetragonal martensite in quenched steels is a solid solution of carbon in iron, the lattice constants were calculated from the radii of the spheres of action of the iron and carbon atoms. The result obtained agreed fairly well with the observed values, thus confirming the solid solution theory.

Surface Magnetisation and Block Structure of Ferrite. W. C. Elmore and L. W. McKeehan. (American Institute of Mining and Metallurgical Engineers, 1935, Technical Publication No. 656; Metals Technology, 1935, vol. 2, Dec., No. 8). A study was made of the block structure of ferrite and silicon ferrite, as revealed by surface magnetisation. The medium employed to expose the effect of magnetisation was a colloidal suspension of ferromagnetic Fe_2O_3, together with gum arabic in water. The polished specimens were coated with the colloid and subjected to the influence of a magnetic field. The authors describe and interpret the patterns obtained in this way, on the basis of the theory of blocks. The size of these blocks appears to be about 2 μ, but they may be smaller or larger than this. When a transverse magnetic field was applied to a specimen previously subjected to a longitudinal field, the effect of the latter was found to persist, showing that the magnetic history of the material is of considerable importance.

The Study of Metallic Crystals. E. Schmid. (Seventh International Congress on Mining, Metallurgy and Applied Geology, Paris, Oct. 20–26, 1935: Revue de Métallurgie, Mémoires, 1935, vol. 32, Dec., pp. 638–648). In this general study of metallic crystals, the author discusses the structure of the lattice and mechanisms of transformation, the physical properties of crystals,

plastic deformation, and the separation of supersaturated phases, and gives an explanation of the properties of polycrystalline commercial products on the basis of the properties of a single crystal.

The Orientation of Crystals in Silicon Iron. R. M. Bozorth. (Transactions of the American Society for Metals, 1935, vol. 23, Dec., pp. 1107–1111). The X-ray examination of silicon iron prepared by Goss (another worker in the same field) and supplied to the present author showed that the component crystals are orientated so that a [001] direction is parallel to the direction of rolling and a (110) plane lies in the rolling plane. This is contrary to the result reported by Goss. The differences in the magnetic properties in various directions in the sheet are explained in terms of the properties of the single crystals, and it is concluded that the high permeability of this type of silicon iron, compared with other silicon irons, is due to the favourable orientation of the crystals composing it.

Origin and Growth of Graphite Nuclei in Solid and Liquid Iron Solutions. H. A. Schwartz and W. Ruff. (American Institute of Mining and Metallurgical Engineers, 1935, Technical Publication No. 655; Metals Technology, 1935, vol. 2, Dec., No. 8). The authors record some results of an investigation into the origin and growth of graphite flakes and nodules in mottled iron, and in malleable iron. Data on the growth and size distribution of graphite nuclei in white iron subjected to heat treatment are presented, and an account of the influence of the melting conditions on the nucleation of white iron is also furnished. The development of graphite flakes in grey irons is treated, together with an analysis of the effect of the graphite distribution on the physical properties of the iron. The authors remark that the number of nuclei forming in white cast irons is not determined by the freezing and melting conditions alone, but also by the temperature at which the nuclei are caused to grow. The nodules may be divided into two groups: Small nodules, which are very numerous, but which do not grow in size, and larger nodules, fewer in number, but subject to growth. There is also evidence to show that nucleation may be affected by the existence of vestigial nuclei furnished by the materials charged into the furnace. The shape of the nuclei, as well as their number, appears to have an effect on the graphitising rate. The nuclei which give rise to graphite flakes in mottled iron are very much less numerous than those which form nodules on secondary graphitisation; this may, perhaps, be attributed to greater supercooling in the case of white irons. Experiments on the effect of furnace conditions suggest that oxides, particularly ferrous oxide, may play an important part in nucleation. In conclusion, it is pointed out that the large number of variables involved makes general inferences difficult.

The Interpretation of the Equilibrium Diagram. N. P. Allen, (Proceedings of the Staffordshire Iron and Steel Institute, 1934–35. vol. 50, pp. 98–119).

Beryllium. R. Gadeau. (Seventh International Congress on Mining, Metallurgy and Applied Geology, Paris, Oct. 20–26, 1935 : Revue de Métallurgie, Mémoires, 1935, vol. 32, Dec., pp. 627–637). The author reviews the ores of beryllium, the preparation of beryllium salts and the metal, the properties of the element, the uses of beryllium and its salts, and the alloys of beryllium. Very brief reference is made to the properties of iron-beryllium alloys.

The Iron/Carbide/Silicon Diagram. A. Dawans. (Revue Universelle des Mines, 1935, vol. 11, Dec., pp. 541–552). The author first reviews the iron-carbon, iron-silicon, and silicon-carbon binary diagrams, and then presents a study of the iron-carbon-silicon ternary diagram ; in conclusion he gives some considération to those parts of the diagram which have not so far been well determined.

The Iron-Tantalum Diagram. (Metallurgist, 1935, Dec. 27, pp. 85–86). An English summary of some work carried out by Jellinghaus on the iron-tantalum diagram is furnished.

CORROSION OF IRON AND STEEL

(Continued from p. 112 A)

The Embrittlement of Boiler Steel.—IV. E. P. Partridge and W. C. Schroeder. (Metals and Alloys, 1935, vol. 6, Nov., pp. 311–316). In the fourth instalment in the series on the above subject a number of tests on the hydrogen embrittlement produced by immersion in caustic solutions is described, and the results obtained by the various investigators are examined. Attention is also given to the influence of the temperature and composition of the solution, and the type of steel used. The following conclusions are drawn: (1) The cracking of steel subjected to chemical attack while under stress consistently commences in a region where the local stress is greater than the average; (2) an unknown but probably very high local stress is necessary to initiate cracking; (3) the yield point at room temperature is not a fundamental criterion of the stress necessary to cause cracking; (4) no definite experimental evidence has been produced to show whether embrittlement failure is due to intercrystalline corrosion, to the action of high local stresses on steel made brittle by hydrogen, or to some other type of action; (5) most steels are subject to embrittlement, although there is some question concerning a possible greater resistance in the case of non-ageing steel.

The Embrittlement of Boiler Steel.—V. E. P. Partridge and W. C. Schroeder. (Metals and Alloys, 1935, vol. 6, Dec., pp. 355–360). The fifth and final instalment on the above subject is concerned with the behaviour of steel under the influence of repeated stress and chemical attack. The work of various investigators at both low and high temperatures is critically summarised. The article concludes with a final brief outline of the causes of embrittlement failure in boiler steel. (*See* Journ. I. and S.I., 1935, No. II., p. 478).

Corrosion from Products of Combustion of Gas.—Part III. Tube Experiments. (Institution of Gas Engineers, 1935, Communication No. 121). The results are reported of an examination of the action of products of combustion of town gas upon typical materials used in the construction of gas appliances, more especially of the effects of burning gases of a lower sulphur content than is at present common in town gas.

ANALYSIS

An Approved Method for the Determination of Aluminium and Alumina in Steels. G. T. Motok and E. O. Waltz. (Iron Age, 1935, vol. 136, Dec. 26, pp. 23–25). A residue method is described, which is as follows: The drillings are dissolved in HCl, and the solution is filtered and washed with dilute HCl, hot water, and hot Na_2CO_3 solution; this gives filtrate (*a*) and residue (*b*). Residue (*b*) is ignited, dissolved in HCl, oxidised with HNO_3, rendered alkaline with NaOH, diluted, boiled, and allowed to stand. It is filtered, and the filtrate is oxidised with bromine water and HNO_3, made alkaline with ammonia, boiled, and filtered. The $Al(OH)_3$ is washed through with HCl, reprecipitated, filtered, and washed. The filter papers are combined and the silica is volatilised off with HF and H_2SO_4. The residue is strongly ignited, and weighed as Al_2O_3. A blank should be run. Filtrate (*a*) is examined for aluminium. Ammonium phosphate and ammonia are added to produce a slight turbidity, which is cleared with HCl. The solution is diluted, boiled, and to it a solution of $Na_2S_2O_3$ is added, followed by acetic acid; it is again boiled and the $AlPO_4$ is filtered off and ignited. Contaminating oxides are removed as for residue (*b*), and the aluminium is weighed as the oxide, Al_2O_3. The recovery of aluminium, in the metallic and oxidised forms, is stated to average 90%. The authors give details of the technique adopted, and a comparison of the recovery obtained by different methods, including that described.

The Estimation of Beryllium, Aluminium, and Magnesium in Ferrous Metals. R. Gadeau. (Revue de Métallurgie, Mémoires, 1935, vol. 32, Sept., pp. 398–400). The author gives very brief details of methods for estimating the beryllium, aluminium, and magnesium contents of irons and steels.

The Application of Potentiometric Volumetric Analysis in Ironworks Laboratories. VI.—The Estimation of Cobalt and Manganese by Means of Potassium Ferricyanide. P. Dickens and G. Maassen. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1935, vol. 17, No. 16, pp. 191–202). A new volumetric method for the potentiometric determination of cobalt in ammoniacal solution of ammonium citrate by oxidation with potassium ferricyanide is described. The oxidation is effected according to the equation:

$$1Co^{\cdot\cdot} + 1Fe(CN)_6''' \longrightarrow 1Co^{\cdot\cdot\cdot} + 1Fe(CN)_6''''.$$

The titration can be carried out without the exclusion of air. The difficulties, due to iron, chromium and vanadium, encountered on applying the method to steels were overcome; the method can be

used in the presence of unlimited quantities of nickel. Manganese is estimated in a similar solution in the same way :

$$1Mn^{\cdot\cdot} + 1Fe(CN)_6''' \longrightarrow 1Mn^{\cdot\cdot\cdot} + 1Fe(CN)_6''''.$$

When cobalt and manganese are present together the titration gives the sum of these two elements.

Bismuthate Method for Manganese.—II. B. Park. (Industrial and Engineering Chemistry, 1935, Analytical Edition, vol. 7, Nov., p. 427). It is noted that in the reaction between arsenite and permanganate in the bismuthate method for manganese, the manganese is not reduced to the bivalent state. The use of certain catalysts has been proposed, notably potassium iodate, iodine, and osmium tetroxide. The effect of these catalysts was studied, and on the basis of the results a modified bismuthate method is suggested in which osmium tetroxide is the catalyst employed.

Colorimetric Determinations of Molybdenum. L. C. Hurd and H. O. Allen. (Industrial and Engineering Chemistry, 1935, Analytical Edition, vol. 7, Nov. 15, pp. 396–398). The authors record the results of a study of the variables involved in the colorimetric determination of molybdenum by the thiocyanate-stannous chloride method. In each case the colour persistence was plotted against the elapsed time. They present curves showing the effect of varying amounts of hydrochloric acid, potassium thiocyanate, stannous chloride, stannic chloride, sulphuric acid, and of certain non-aqueous extractors, including ether, butyl acetate, and cyclohexanol. In the light of their results the authors recommend that the concentration of hydrochloric acid be 5%, the potassium thiocyanate 0·6%, and the stannous chloride above 0·1%.

Contribution on the Colorimetric Determination of Molybdenum in Steel and Cast-Iron Samples with the Aid of the Pulfrich Photometer. O. Keune. (Technische Mitteilungen Krupp, 1935, vol. 3, Nov., pp. 215–218). On the basis of the colour reaction which occurs between molybdate in weakly acid solution and potassium thiocyanate and zinc chloride, a method has been proposed for the colorimetric estimation of molybdenum by matching the colour with that of a standard solution. This method, however, is beset with difficulties, which the present author enumerates; he shows how in the photometric method they can be overcome. He gives the compositions of the special solutions required, describes the drawing up of the calibration curves for the instrument, and explains how to select the appropriate colour filters; the manipulation in making an assay is exactly the same as that in calibrating the instrument.

Rapid Determination of Nickel in 18 and 8 and other High Chromium Steels and Alloys. F. P. Peters. (Metals and Alloys, 1935, vol. 6, Oct., pp. 278–279). When the volumetric estimation of nickel in the presence of chromium is attempted, using the cyanide method, the strong green colour imparted by the chromium renders

the detection of the end-point very difficult. If, however, the chromium is oxidised to the hexavalent condition the sombre green solution becomes bright yellow, and the end-point (turbidity) can be observed without difficulty. In the method described by the author the oxidation of the chromium is effected by evaporating the solution with perchloric acid ($HClO_4$), and the subsequent titration is carried out in the usual way, using potassium cyanide and titrating back with silver nitrate. The method is stated to be rapid and accurate.

Determinations of Oxygen and Nitrogen in Steel. J. Chipman and M. G. Fontana. (Industrial and Engineering Chemistry, 1935, Analytical Edition, vol. 7, Nov. 15, pp. 391–395). An improved method of estimating the oxygen and nitrogen in steel has been devised, in which certain modifications to the furnace and absorption apparatus have been incorporated. The shell of the furnace is a silica tube, the upper end of which is water-cooled and sealed by a brass head, the lower end being encircled by an induction coil. The crucible is of graphite, and may be heated to 1900° C. by the high-frequency induction coil; two concentric graphite radiation shields prevent the silica tube from overheating. The specimen is supported by means of nickel wire from a stainless steel windlass in the brass head; the latter is also furnished with a glass window for pyrometer sighting, and an outlet to the pump and absorption train. The graphite crucible contains a small graphite plug to prevent spattering, and the crucible assembly rests on a magnesia base at the bottom of the silica tube. The chief features of the analytical train are a two-stage mercury diffusion pump, backed by a "megavac" oil pump; the McLeod gauge; the absorption tubes, one containing ascarite for removing carbon dioxide, and the other phosphorus pentoxide for absorbing the water; and the copper oxide furnace. The improved method requires about 75 to 85 min., and is stated to be more accurate than the methods previously used; in addition, a very small blank correction is necessary. In general, the oxygen from the alumina in the steel was also recovered.

Colorimetric Determination of Silicon in the Presence of Iron and Elements Accompanying Iron. H. Pinsl. (Archiv für das Eisenhüttenwesen, 1935, vol. 9, Nov., pp. 223–230). In the method described the colorimetric estimation of silicon in steels can be effected without a phosphate precipitation and filtration; this is due to the addition of sodium fluoride after the molybdate reaction. The effect of sodium fluoride on the reactions of silica and phosphate with molybdenum is discussed. With unalloyed steels the method may be worked with or without colour compensation; the former process is also applicable to all alloy steels which will dissolve completely in acid, even those with high titanium contents. At the moment the method is not usable for high-silicon pig and cast irons.

Progress in Spectrographic Analysis. T. A. Wright. (Metals and Alloys, 1935, vol. 6, Sept., pp. 229–234; Oct., pp. 289–292). These articles constitute a correlated abstract of six papers on aspects of spectrographic analysis. They contain notes on the spectrographic analysis of non-ferrous and ferrous materials, sampling, electrodes, and the precision and range of the methods adopted. In the second article some details of the procedures employed by various workers in the field of spectrographic analysis are presented.

Application of the Spectrograph to the Determination of Carbon in Steel. F. H. Emery and H. S. Booth. (Industrial and Engineering Chemistry, 1935, Analytical Edition, vol. 7, Nov., pp. 419–421). The authors record the results of a study of the application of the spectrograph to the determination of carbon in steel. They employed the internal standards method and determined the relative intensities of carbon and iron by the logarithmic wedge sector; they compare the methods of excitation used, and the results obtained on steels of different carbon contents. The authors conclude that although the aperiodic spark detects gross changes in the oxygen content, its potential appears to be insufficient to bring out variations in the carbon content; perhaps more intense excitation would be successful.

Contributions on Applied Spectrography in Metal-Working Industries. G. Heidhausen. (Mitteilungen aus den Forschungsanstalten des Gutehoffnungshüttekonzerns, 1935, vol. 4, Dec., pp. 59–70). This is the first of a series of articles which will be devoted to the subject of the practical application of spectrography in the chemical testing of materials in a mechanical engineering works with wide interests. The author restricts himself almost entirely to the quantitative aspect of spectrum analysis and to those requirements and problems of materials testing which arise out of the building of machinery. The present article gives an illustrated description of the spectrographic apparatus in the laboratories of the Machinenfabrik Augsburg-Nürnberg A.-G. (MAN).

Spectroscopic Analysis of Steels—The Influence of Non-Homogeneous Materials. W. R. Brode. (Proceedings of the American Society for Testing Materials, 1935, vol. 35, Part II., pp. 47–56).

The Purification of Graphite Electrodes for Spectrochemical Analysis. G. W. Standen and L. Kovach, jun. (Proceedings of the American Society for Testing Materials, 1935, vol. 35, Part II., pp. 79–85). The authors discuss methods for the purification of the graphite rods commonly used as arc electrodes in spectrochemical analysis. The reliability of the analysis depends largely on the purity of the electrodes used.

The Application of the Theory of Sampling to Coal Sampling. A. B. Manning. (Journal of the Institute of Fuel, 1935, vol. 9, Dec., pp. 132–136). In this paper an attempt is made to indicate the lines along which a theory of coal sampling (for ash determina-

tion) can be developed, and how it can be applied to the estimation of the size of sample it is necessary to take to ensure a predetermined degree of accuracy in the determination of the ash content. The subject is treated mathematically; the methods outlined permit the standard deviation (or probable error) of the ash determination of a sample of coal, or the weight of a sample to be taken to give a predetermined standard deviation to be estimated when certain characteristics of the coal and the sampling procedure are known.

The Determination of Nitrogen in Coal by the Kjeldahl Method, using Selenium as a Catalyst. H. E. Crossley. (Chemistry and Industry, 1935, vol. 54, Nov. 1, 367T–369T). The author explains that the evidence concerning the efficacy of selenium as a catalyst in the estimation of nitrogen by the Kjeldahl method is somewhat conflicting. He has therefore undertaken experiments on the use of selenium as a catalyst in which the conditions of performing the estimation were varied. The effects of the rate of heating, the amount of moisture present in the acid-coal mixture, the temperature of the boiling solution, and the length of the " afterboiling " period were all investigated. In the light of the results so obtained he describes a suitable analytical procedure, using selenium as a catalyst in a modified Kjeldahl method.

The Determination of Alkalis in Silicates with Special Reference to High-Alumina Refractories. E. B. Read. (Journal of the American Ceramic Society, 1935, vol. 18, Nov., pp. 341–346). The estimation of alkalis in high-alumina refractories is usually uncertain and difficult. The author describes two methods of effecting the decomposition necessary for analytical purposes. In the first, the J. Lawrence Smith method, the customary fusion with NH_4Cl and $CaCO_3$ was adopted, at a final temperature of 1200° C. and in a platinum crucible, care being taken to cool the top of the crucible in order to prevent volatilisation of the alkalis; for this purpose a small copper water-cooling coil was employed. The second method depends on the decomposition of the sample with a mixture of nitric, sulphuric, and hydrofluoric acids. The alkalis may be determined after the elimination of the other elements; magnesia is removed with 8-hydroxyquinoline and the alkalis are weighed as sulphates. Experimental data are given pertaining to these procedures when used for the analysis of several types of materials.

BOOK NOTICES

McWilliam, A., and P. Longmuir. "*General Foundry Practice.*" Fourth edition, revised throughout and enlarged by P. Longmuir. 8vo, pp. viii + 457 + 303 illustrations. London, 1935: Charles Griffin and Co., Ltd. (Price 21s.)

The demand for a new edition of this text-book shows that it is well known to students, and it can be warmly commended as a standard work. It has been brought reasonably up-to-date by the surviving author, Dr. Longmuir. It deals as comprehensively as the space permits with foundry practice in grey iron, malleable cast iron, steel and non-ferrous castings, and with the principles underlying their metallurgical production. The chapters on foundry practice occupy the bulk of the book, and no important section is omitted. Where necessary, references are given to other more advanced works. While more comprehensive works on founding and its metallurgical basis are in existence abroad, this book remains the best for English readers.

75 Years of the Verein Deutscher Eisenhüttenleute, 1860 to 1935. (Stahl und Eisen, 1935, vol. 55, Nov. 28, pp. 1253–1450).

The whole of this issue of *Stahl und Eisen* is devoted to a detailed history of the Verein deutscher Eisenhüttenleute, which Society celebrates its seventy-fifth anniversary this year (1935). On December 14, 1860, the Technischer Verein für Eisenhüttenwesen was called into being by a number of important men in the West-German iron and steel industry; at the turn of the year 1880–81 this body was renamed with its present title. The present history is divided into five parts, dealing with the periods 1860–1880, 1880–1905, 1905–1914, 1914–1918 and 1918–1935, and presents an account of the genesis and development of the Society, its work and that of its many technical committees, as well as of the activities in and the development of the iron and steel industry. Numerous portraits are reproduced of outstanding men in the industry, both German and foreign.

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STALLMANN, K. "*Der Stahlwerksverband in seinen internationalen Beziehungen.*" (Berlin (Handels-Hochschule), Wirtschaftswiss. Diss.) 8vo, pp. 124. Dortmund, 1935: E. Teuber.

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ZEERLEDER, A. von. "*Technologie des Aluminiums und seiner Leichtlegierungen.*" Zweite verbesserte Auflage. 8vo, pp. 300. Leipzig, 1935: Akademische Verlagsgesellschaft m.b.H. (Price 12,60 gold marks.)

REFRACTORY MATERIALS

(Continued from p. 41 A)

The Effect of Oxides of Iron and Chromium and a Reducing Atmosphere on the Rate of Tridymite Formation in a Silica Brick Batch. T. R. Lynam and W. J. Rees. (Bulletin of the British Refractories Association, 1932, Aug., No. 28 : Transactions of the Ceramic Society, 1935, vol. 34, Dec., pp. 507–514). Experiments were carried out on silica brick batches in which small quantities of iron oxide, chromic oxide, carbon, Prussian blue, or Siemens' slag were incorporated. One briquette from each mix was fired in a rapid gas-fired furnace, and the remainder were fired in a silica kiln under oxidising or reducing conditions. The authors present data on the linear expansion, porosity, powder density, and appearance under the microscope. Bricks burned under reducing conditions showed decidedly less tridymite than those fired under normal kiln conditions. Reducing conditions did not appear to increase the activity of iron oxide in accelerating the formation of tridymite, although the evidence on this point cannot be regarded as conclusive. Chromium oxide was less effective than iron oxide in promoting the formation of tridymite. Siemens' slag and Prussian blue had a very favourable effect on the rate of formation of tridymite.

The Use of Penetrating Radiations in the Measurement of the Porosity of Refractory Brick. J. B. Austin. (Journal of the American Ceramic Society, 1936, vol. 19, Feb., pp. 29–36). The possibility of using the absorption of X-rays or gamma rays by refractory brick as a measure of its porosity was investigated. Both types of radiation were found to be suitable and yielded good results, gamma rays being somewhat better adapted to this purpose than X-rays.

Loading Device for Load-Test Furnace. J. L. Carruthers. (Journal of the American Ceramic Society, 1936, vol. 19, Feb., pp. 36–38). A loading device for use in making the standard load test on refractory brick is described. It consists of two steel shafts loaded with weights and mounted in a steel frame so as to provide direct vertical loading on the two specimens under test.

Refractory Problems in Basic Alloy Steel Production. G. Soler. (Bulletin of the American Ceramic Society, 1935, vol. 14, Dec., pp. 383–388). The various purposes for which refractories are used in a modern alloy steel plant are outlined, and the connection between the quality of the steel and the cost of the refractories is considered. The causes of failure and methods of testing refractories are discussed.

Designs New Checker for Regenerator Chambers. M. K. Mellott. (Steel, 1935, vol. 97, Dec. 23, p. 42). A new design of checker brick,

known as the "Superior," is described. Each checker interlocks with adjoining checkers at all four corners; the free area amounts to 52½% when "Superior" bricks are used, compared with 33% with the conventional form of construction. On the other hand, the heating surface per cu. ft. of space is increased by 18%.

Determination of Thermal Conductivity of Refractories. P. Nicholls. (Bulletin of the American Ceramic Society, 1936, vol. 15, Feb., pp. 37–51). This paper is a report to Sub-Committee C-8 on Heat Transfer and Refractory Insulation of the American Society for Testing Materials. The author analyses six reports by various investigators, who used six different methods of determining the thermal conductivity of standard specimens of silica brick and firebrick. The results obtained by these workers differed widely. The sources of possible error in each method are suggested, and a scheme for a thorough analytical investigation of the problem is outlined.

Some Uses of Insulating Fire Brick in Modern Foundry Practice. C. L. Norton. (Transactions of the American Foundrymen's Association, 1935, vol. 43, pp. 55–58). The merits and demerits of insulating fire brick used in the melting of non-ferrous alloys and in the heat treatment of steel castings are outlined. The author shows that the adoption of insulating refractory brick in non-ferrous foundries has resulted in considerable savings, and that in the annealing of steel castings reductions in cost of 30% to 50% have been recorded.

Steel Ladle Refractories. (Metallurgia, 1936, vol. 13, Jan., pp. 93–94). The factors which influence the performance of the refractories for ladle nozzles, stoppers, and linings are discussed.

FUEL

(Continued from pp. 116 A–118 A)

The Specific Heats of Gases as an Aid in the Calculation of Equilibria. C. Schwarz. (Archiv für das Eisenhüttenwesen, 1936, vol. 9, Feb., pp. 389–396). The values for the specific heats of the more important gases contained in the latest American reports—probably the most accurate—are represented by means of approximate formulæ, and have been further developed so that they can be used for both thermotechnological calculations and also for working out the equilibria of gas reactions.

Automatic Combustion Control for Furnaces and Boilers Improved. E. W. Wagenseil. (Steel, 1936, vol. 98, Feb. 17, pp. 54, 65). A brief indication of the extent to which automatic combustion control has been improved is given.

New Forms for the Prandtl Equation for Heat Transfer. J. Kuprianoff. (Zeitschrift für technische Physik, 1935, vol. 16, p. 13 : Zeitschrift des Vereines deutscher Ingenieure, 1936, vol. 80, Feb. 8, pp. 159–160). The author discusses Prandtl's equation for the transmission of heat between fluids and the tube wall under conditions of turbulent flow, and indicates new forms for it.

Bulk Density, Moisture Content, and Fineness of Fine Coal. R. Stuchtey. (Technische Mitteilungen Krupp, 1936, vol. 4, Feb., pp. 19–21). The results of experiments designed to show the relation between the bulk density, moisture content, and fineness of fine coal are recorded. The bulk density was found to decrease as the fineness increased; the density curves showed marked minima, which did not occur at a constant moisture value, but moved towards higher moisture contents as the fineness increased. The density of dry fine coal—for instance, briquetting coal with 0–5% of moisture—was dependent not only on the fineness, but also very much on even very small variations in the moisture content.

The Oxidisability of Coal. E. Stansfield, W. A. Lang, and K. C. Gilbart. (Annual Reports of the Research Council of Alberta, 1933 and 1934 : Fuel in Science and Practice, 1936, vol. 15, Jan., pp. 12–14). In the method of estimating the oxidisability of coals which is described the sample is continuously ground in a ball mill, and the oxygen absorbed from the air is replaced by fresh oxygen from a gasholder; this supply is metered. The humidity is maintained constant during the test, and any carbon dioxide evolved is absorbed by reagents. Some typical results are furnished.

Nomenclature of Coal Petrography. W. J. Jongmans, R. G. Koopmans, and G. Roos. (Fuel in Science and Practice, 1936, vol. 15, Jan., pp. 14–15). One of the subjects discussed at the Second International Congress for the Study of the Stratigraphy of

the Carboniferous Rocks, held at Heerlen in September 1935, concerned the terms used to define the petrological coal units. The substance of a memorandum embodying the recommendations of the conference is reproduced.

Concentration of the Banded Ingredients of Illinois Coals by Screen Sizing and Washing. L. C. McCabe. (American Institute of Mining and Metallurgical Engineers, 1936, Technical Publication No. 584).

Pneumatic Cleaning of Coals. O. Seutin. (Seventh International Congress on Mining, Metallurgy and Applied Geology, Paris, Oct. 20–26, 1935, Mining Section, vol. 2, pp. 470–473). The Limburg-Meuse Collieries (Belgium) are introducing the Bruay-Soulary method of dry coal-cleaning for fine material up to 5 mm. in size; larger material will be wet-cleaned as before. After explaining why dry-cleaning is being applied, the author describes the apparatus and gives brief notes on results obtained with similar plant.

Some Observations on the Practical Operation of Pneumatic Cleaning Tables for Coals. Steinmetzer. (Seventh International Congress on Mining, Metallurgy and Applied Geology, Paris, Oct. 20–26, 1935, Mining Section, vol. 2, pp. 474–480). A general discussion of the phenomena entering into the process of cleaning coals by means of pneumatic tables.

Screening and Washing Plant at Mauchline Colliery. (Iron and Coal Trades Review, 1936, vol. 132, Feb. 21, pp. 347–348). An account is given of the tippling and screening gear and the coal washery in use at the Mauchline Colliery of Messrs. Bairds and Dalmellington, Ltd., Prestwick. Norton automatic washers are in use, and the normal capacity of the plant is 75 tons per hr.

Modern Developments in Wet Washing. J. E. D. Speakman. (Armstrong College Mining Society: Iron and Coal Trades Review, 1936, vol. 132, Feb. 28, pp. 397–398). The author describes the Hoyois and Barvoys processes of coal washing and gives tabulated results of the operation of the plants under everyday working conditions.

The "Hoyois" Automatic Process of Washing Coal by Currents of Water. L. Hoyois. (Seventh International Congress on Mining, Metallurgy and Applied Geology, Paris, Oct. 20–26, 1935, Mining Section, vol. 2, pp. 436–447). The Hoyois coal-washing process and two plants working it are described.

Note on a Hydropneumatic Washer Intended Particularly for Raising the Value of Fine Coals. R. Toubeau. (Seventh International Congress on Mining, Metallurgy and Applied Geology, Paris, Oct. 20–26, 1935, Mining Section, vol. 2, pp. 448–452). A hydropneumatic washer for fine coals is described, and some results obtained with it are recorded.

The Washing of Raw Coal, in its Relations to the Utilisation of the By-Products of Washeries. M. Brun. (Seventh International Congress on Mining, Metallurgy and Applied Geology, Paris, Oct. 20–26, 1935, Mining Section, vol. 2, pp. 453–458). The author

enumerates and comments on some of the problems encountered in the washing of coals with regard to the fine material, and indicates means for solving them.

Contribution on the Theory of Washing. W. Budryk. (Seventh International Congress on Mining, Metallurgy, and Applied Geology, Paris, Oct. 20–26, 1935, Mining Section, vol. 1, pp. 208–218). The author discusses the theory of the underlying principles of the washing of ores, &c.

Preparation Methods and Plants for Bituminous Coals in the U.S.S.R. E. Werchowsky. (Seventh International Congress on Mining, Metallurgy and Applied Geology, Paris, Oct. 20–26, 1935, Mining Section, vol. 2, pp. 420–432). The author discusses the petrological characteristics and chemical compositions of Russian coals, their classification curves and washability, and methods of cleaning used, and gives some details of the coal-washeries in the U.S.S.R.

Coal Washing. G. Schileru. (Seventh International Congress on Mining, Metallurgy and Applied Geology, Paris, Oct. 20–26, 1935, Mining Section, vol. 2, pp. 433–435). A brief note on washing tests made on the coal from one of their seams by the Petrosani Co., Rumania.

Washing, Pneumatic Cleaning, and Flotation of Coals. Vieux. (Seventh International Congress on Mining, Metallurgy and Applied Geology, Paris, Oct. 20–26, 1935, Mining Section, vol. 1, pp. 196–207). A general discussion of the cleaning of coal by wet, dry, and flotation methods. Tables give data on the outputs of a number of coal mines in France, including figures for the tonnages cleaned.

The Cleaning of Coal by Means of a Dense Liquid. Simultaneous Separation *in Situ* of Pure Coal, Intermediates and Schists. Berthelot. (Seventh International Congress on Mining, Metallurgy and Applied Geology, Paris, Oct. 20–26, 1935, Mining Section, vol. 2, pp. 481–484). The author enumerates the various processes of coal cleaning in which dense liquids are used, and describes the plant at the Sophia-Jacoba colliery.

A New Fuel : Pure Coal and its Applications. M. F. Bertrand. (Seventh International Congress on Mining, Metallurgy and Applied Geology, Paris, Oct. 20–26, 1935, Mining Section, vol. 2, pp. 485–495). Vitrain is usually the most pure of the constituents in coal; its ash content may be as low as 0·2% (representative analyses are listed). The author first indicates the uses to which pure coal (vitrain) may be put, and then describes its preparation (by washing processes). In conclusion, he refers to its use for the manufacture of electrodes for electrolytic purposes.

Treatment of Coal-Bearing Slimes Derived from Fat Coals and Containing a High Proportion of Ash. C. Hanot. (Seventh International Congress on Mining, Metallurgy and Applied Geology, Paris, Oct. 20–26, 1935, Mining Section, vol. 2, pp. 459–469). A process and plant for treating high-ash coal-bearing slimes derived

from fat coals are described and illustrated. Some figures of operating costs and profits are given.

Flocculation in Theory and Practice. (Colliery Engineering, 1936, vol. 13, Feb., pp. 45–52). The nature of colloids, the theory of flocculation, and the application of the theory to the clarification of coal-washery waters are discussed.

The British By-Product Industry in 1935. (Coal Carbonisation, Supplement to Colliery Engineering, 1936, vol. 2, Feb., pp. 27–36, 40). An account of the progress made by the by-product coking industry during 1935 is given, and the major installations put down during the year are described.

British Coke-Oven Machinery in Holland. (Engineer, 1936, vol. 161, Feb. 14, pp. 174–175). A description of a coke-pusher installed at the Maurits Mine coke-oven plant of the Staatsmijnen, Lutterade, Holland, is presented.

The Mechanism of Cokefaction and the Characteristic Properties of Coking Coals. H. A. J. Pieters, H. Koopmans, and J. Hovers. (Seventh International Congress on Mining, Metallurgy and Applied Geology, Paris, Oct. 20–26, 1935, Mining Section, vol. 2, pp. 496–506). The authors present a study of the melting, swelling, plasticity, and thermal decomposition of a series of vitrains containing various amounts of volatile matter. The plasticity was measured by a new method. A combination of the results obtained gives the solution of the problem of characterising coking coals, and explains clearly why there is only a single limited group of coals which can be used for making coke.

The Balance of the Phosphorus in the Coal in Coke-Oven Operation. W. Demann and W. Ter-Nedden. (Technische Mitteilungen Krupp, 1936, vol. 4, Feb., pp. 1–6). After describing an improved method of estimating the phosphorus in coke, the author presents a phosphorus balance, which shows that practically the whole of the phosphorus remains in the coke, the by-products being almost free from that element; wet quenching does not leach out or otherwise remove any of the phosphorus. The element exists almost entirely in inorganic combination. The possibility of decreasing the phosphorus content of coke is discussed; the addition of chemicals with the object of removing it during the coking process leads to no result at ordinary coking temperatures.

The Manufacture of Coke and Semi-Coke in France. Vigier. (Seventh International Congress on Mining, Metallurgy and Applied Geology, Paris, Oct. 20–26, 1935, Mining Section, vol. 1, pp. 219–229). A general review of the coking and low-temperature carbonisation industries of France.

Investigations on Wash-Oil Problems. W. Demann and W. Brösse. (Technische Mitteilungen Krupp, 1936, vol. 4, Feb., pp. 9–16). The authors present the results of their investigation of the reaction of sulphuretted hydrogen with wash-oil and the effect on the thickening of the oil.

Phosphorus in Tar. W. Demann and F. Grimmendahl. (Technische Mitteilungen Krupp, 1936, vol. 4, Feb., pp. 6–7). The authors present the results of an investigation of the distribution of the small amount of phosphorus that enters into coke-oven tar between the various tar fractions.

Comparative Investigations on Fresh and Stored Cokes. W. Demann. (Technische Mitteilungen Krupp, 1936, vol. 4, Feb., pp. 17–19). During the years of trade depression, Krupp's coke-oven plants put large quantities of coke into store. Later, as trade revived, this stored coke was supplied to the blast-furnace plants. The latter, however, reported operating troubles in the use of this coke mixed with other coke. It was suggested that the weather, particularly frost, in conjunction with the higher moisture content, set up structural changes in the coke, which became evident in the operation of the blast-furnace as scaffolding and greater abrasion. However, the laboratory tests described in this article, made on stored coke and fresh coke, showed that there was little or nothing to choose between them. Large-scale tests in a blast-furnace, run either entirely on stored coke or entirely on fresh coke, showed that with stored coke there was only a very slight increase in the coke consumption (referred to " pure " coke).

Producer Gas for Heating Coke Ovens. C. Dinsdale and E. A. Curtis. (Coke Oven Managers' Association: Colliery Guardian, 1936, vol. 152, Jan. 24, pp. 160–162; Jan. 31, pp. 201–202). An account of the Koppers producer installed at the coke-oven plant of the Blackwell Colliery Co. is given. In discussing the performance of the producer the authors point out that it enables low-quality fuel to be utilised, and allows an equivalent amount of coke-oven gas to be marketed; the actual efficiency of carbonisation is scarcely affected.

Operating Experiences with Electrical Tar Removal. H. Eiring. (Glückauf, 1936, vol. 72, Feb. 15, pp. 163–167). The author gives an account of his experience with the Lurgi electrical process of removing tar from gas; under all conditions of temperature, and despite variations in the tar content of the untreated gas, a truly clean gas, free from tar fog, was always produced. The influence of this freedom from tar fog on the subsequent treatments (*e.g.*, oil recovery and desulphurisation) is discussed.

The Hydrocyanic Acid Content of Coke-Oven Gas. W. Ter-Nedden. (Technische Mitteilungen Krupp, 1936, vol. 4, Feb., pp. 8–9). The author presents data on the content of hydrocyanic acid in coke-oven gas at the various stages of its treatment.

Colloidal Fuel. A. B. Manning and R. A. Acton Taylor. (Institution of Chemical Engineers, Feb. 21, 1936). After summarising the advantages which attend the use of colloidal coal-oil fuel, and describing some of the large-scale tests which have been carried out with this type of fuel, the authors go on to discuss some of the problems connected with its use.

PRODUCTION OF IRON

(Continued from pp. 119 A–120 A)

Blast-Furnace Plans and Prospects in the U.S.S.R. B. M. Suslov. (Iron Age, 1936, vol. 137, Jan. 30, pp. 28–29, 79). An outline of the developments in ferrous metallurgy which have been and will be undertaken as part of the second Five-Year Plan is presented.

Rig for Operating Blast-Furnace Bell Reduces Weight on Top Structure. (Steel, 1936, vol. 98, Feb. 3, p. 58). A new type of bell-operating mechanism is described in which the beam and counterweights are dispensed with; instead, a wheel and crankshaft are adopted, the latter being coupled by a connecting rod to the bell rod. It is operated by a counterbalanced hoist.

Influence of the Weather Conditions on Blast-Furnace Operation. K. Guthmann. (Stahl und Eisen, 1936, vol. 56, Mar. 5, pp. 293–297). After touching briefly on previous investigations, the author describes observations made on the influence of the weather conditions on various features of blast-furnace operation. Observations over four years showed that (taking account of the low furnace output at the time) flue-dust production is, above all, decidedly influenced by the weather; rain showers, like water-spraying in the throat, reduced the amount of dust formed. The composition and calorific value of the blast-furnace gas varied in dependence on the dampness of the charges and the moisture in the hot blast; sudden weather changes after dry periods were accompanied by a diminishment of the furnace heat efficiency, due to the decrease in the relative proportion of the indirect to the direct reduction, whereby the coke consumption of the furnace increased in conjunction with the increased decomposition of water in front of the tuyeres. The moisture in the flue gas was increased by more than 100%. All these influences increased the heat expenditure of the furnace in driving out, decomposing, vaporising and superheating the moisture in the charge and in the blast; further, the amount of available iron in the burden was decreased. The author recommends the daily determination of the dust production of a furnace as a means of obtaining a further index of its operation.

Low-Temperature Reduction of Magnetite Ore. G. C. Williams and R. A. Ragatz. (Industrial and Engineering Chemistry, 1936, vol. 28, Jan., pp. 130–133). The effect of various catalysts on the low-temperature reduction of magnetite ore was studied, using metallurgical coke as the reducing agent, at a temperature of 900° C. and under standardised conditions. Certain sodium and potassium compounds (such as sodium carbonate) greatly accelerated the reduction of magnetite ore; no other materials except some barium

compounds exhibited a comparable effect. Hardwood charcoal was observed to be a much more active reducing agent than metallurgical coke and responded well to the catalytic action of sodium carbonate. The catalytic effect of the various compounds is a function of their concentration in the reducing mixture. When using sodium carbonate a considerable loss of sodium occurs, while silica, if present, tends to inhibit its catalysing effect.

On the Reoxidation of Sponge Iron referred to its Quality. M. Okamoto and S. Hibino. (Kinzoku No Kenkyu, 1935, vol. 12, Nov. 20, pp. 493–501). This paper gives the relation between the amount of reduction and carburisation of sponge iron, and the extent to which it oxidises again when exposed to moist air, or air at high temperatures. Fully reduced sponge iron was found to be most resistant to reoxidation in moist air, while sponge iron reduced to the extent of 95–100% and containing 0·0–0·2% of carbon was also found to be resistant to oxidation at high temperatures.

The Carburisation and Decarburisation of Sponge Irons. M. Okamoto and S. Hibino. (Kinzoku No Kenkyu, 1935, vol. 12, Nov. 20, pp. 501–506). The phenomena of the carburisation and decarburisation of sponge irons obtained by the reduction of various magnetic sands and ordinary magnetite with carbon monoxide were studied. The degree of carburisation was found to correspond to the reducibility of the ore. The rates of carburisation of various sponge irons were compared, and the decarburisation at high temperatures was also determined colorimetrically, by estimating the retained carbon.

Simultaneous Production of Iron and Portland Cement in the Rotary Furnace by the Basset Process. R. Durrer. (Stahl und Eisen, 1936, vol. 56, Feb. 27, pp. 268–269). Brief details are first given of the simultaneous production of iron and Portland cement by the Basset process at the Compania Asland Cement Works in Moncada (near Barcelona, Spain); this is followed by a short account of the development of the Basset process.

The Iron Industry in the British Empire. J. W. Reichert. (Stahl und Eisen, 1936, vol. 56, Mar. 5, pp. 297–305). A review of the commercial, statistical, and political aspects of the iron industry in Great Britain and the British Empire.

The Excavations at the Sites of Prehistoric Iron Works in the Siegerland, their Import and the Technical Practice in Comparison with other Discoveries. J. W. Gilles. (Stahl und Eisen, 1936, vol. 56, Feb. 27, pp. 252–263). The author presents an account of the discoveries made during excavations made on the sites of prehistoric iron works in the Siegerland. He discusses the state of development of the art of making iron in the Siegerland in those early times, and deals in detail with the furnaces, process, charcoal, and ores used, the slags and the iron produced, and the further working-up of the metal. He indicates the importance of these discoveries in regard to the history of iron making.

FOUNDRY PRACTICE

(Continued from pp. 121 A–123 A)

Some Points in the Modern Production of Castings. A. Philips. (Foundry Trade Journal, 1936, vol. 54, Jan. 30, pp. 102–107, 110). Among the matters touched on are the following: The physical properties of sands from the foundry point of view; the use of mechanised foundry plant; the properties of alloy cast irons; drying, venting and pouring; and the operation of the cupola.

The Cupola and Good Quality Castings. W. West. (Metallurgia, 1936, vol. 13, Jan., pp. 83–84). The control of the cupola—particularly of the carbon, silicon, and phosphorus contents—in order to obtain a cast iron with a tensile strength between 15 and 20 tons per sq. in. accompanied by perfect soundness in the thicker sections is discussed.

Relation of Air Charge to Cupola Operation. H. V. Crawford. (Transactions of the American Foundrymen's Association, 1935, vol. 43, pp. 303–312). The author discusses the various reactions which take place in the cupola. He describes the functions of each zone, and the way in which improper control of the air supply, coke, and iron charges influences the thermal efficiency and consequently the melting efficiency of such a unit.

Experimental Results with Coke from Coals of Various Geological Origins in the Foundry Cupola. W. Hollinderbäumer. (Giesserei, 1936, vol. 23, Feb. 14, pp. 73–77). The design of the cupola and the management of the combustion process are of prime importance in regard to the behaviour of a given brand of coke and its applicability for general foundry use. The porosity of foundry coke must be low. The graphitisation of the carbon in the coke should not exceed certain limits, which, however, have not so far been determined precisely. Foundry cokes with strengths (determined in the trommel test) of 60% and over can be used in the foundry, provided that the design and operation of the cupola are suited to the use of such cokes. The author's tests show that, in cupolas of a given design, coke brands with high "trommel" strengths give no better results in operation than others that have not been regarded as foundry cokes and are therefore not on the market.

Cupola Practice with Saar Coke. K. Bäsel. (Giesserei, 1936, vol. 23, Feb. 14, pp. 77–78). The author discusses briefly improvement in the quality in the making of Saar coke and cupola operating requirements when melting with this fuel. He mentions the easy reactivity of Saar coke and its low sulphur content of 0·6–0·8%.

Coke Consumption 6% and Melting Charge 100% Scrap! C. Rein. (Giesserei, 1936, vol. 23, Feb. 14, pp. 78–81). The author points out that frequently the coke consumption in a cupola is

worked out on the basis of the charge coke only, whereas account should also be taken of the bed coke and of the coke used for separating the two mixtures as they pass down the cupola when the need for changing the composition of the cast iron arises. Further, by means of cost examples, he shows that the attempt to work with 100% scrap charges is not to be recommended. Working with pig-iron charges is more economical, and prevents increases in the price of scrap as well as the wasting of home-produced scrap in Germany, where the amounts available are only small.

Adding Ferro-alloys in the Cupola. E. K. Smith and H. C. Aufderhaar. (Transactions of the American Foundrymen's Association, 1935, vol. 43, pp. 313–320). The authors indicate the field of use of ferro-alloys, suggest several typical mixtures for various classes of castings, and list the physical properties of the irons obtained from these mixtures. It is stated that by adopting briquettes additional amounts of scrap may be carried in the mixture.

The Possibilities of the Electric Furnace in the Cast Iron and Brass Foundry. A. G. Robiette. (Institute of British Foundrymen: Foundry Trade Journal, 1936, vol. 54, Feb. 27, pp. 173–177). The author discusses the development of the electric furnace for the production of cast iron, the types of furnaces employed, and melting practice. The relative merits and applications of the hearth and rocking arc types of furnaces are dealt with and comparative costs of cupola and electric furnace operation are given.

Cast Iron and the Electric Furnace. A. Le Thomas. (Seventh International Congress on Mining, Metallurgy and Applied Geology, Paris, Oct. 20–26, 1935, Metallurgical Section, vol. I, pp. 257–266: Revue de Métallurgie, Mémoires, 1936, vol. 33, Jan., p. 23). The author first discusses the use of the electric furnace as a means of improving the quality of pig iron; he then deals with its use in the foundry for the production of electric cast iron, touching briefly on the furnaces used; finally, he reviews the properties of electric cast irons and their applications.

The Efficiency of Rapid Malleablising in the Electrically-Heated Malleablising Furnace. R. Buchkremer. (Giesserei, 1936, vol. 23, Jan. 3, pp. 1–4). The author discusses the improvement of the quality of malleable cast iron and the economics of its production by means of the rapid malleablising process, and surveys the various accelerated methods in use. For satisfactory results, rapid malleablising must be carried out in accordance with an exact time/temperature curve, and this is best attained by using an electrically-heated furnace. Constructional types of hood furnaces are illustrated and the general advantages of electric heating are outlined. The cost of malleablising can be reduced by the adoption of a suitable mode of operation.

American Malleable Cast Iron and its Derivatives. R. Gailly. (Seventh International Congress on Mining, Metallurgy and Applied Geology, Paris, Oct. 20–26, 1935, Metallurgical Section, vol. I,

pp. 281–285 : Revue de Métallurgie, Mémoires, 1936, vol. 33, Jan., pp. 38–42). The author discusses the following matters : Specifications for malleable cast iron, melting furnaces, malleablising furnaces, and the modifications of the characteristics of malleable iron resulting from the addition of alloying elements.

Machine Moulding. D. R. Kinnell. (Institute of British Foundrymen : Foundry Trade Journal, 1936, vol. 54, Feb. 13, pp. 137–140). The author discusses various types of hand-operated moulding machines, and their application to the production of light castings.

Metal Moulds for Cast Iron. J. McGrandle. (Institute of British Foundrymen : Foundry Trade Journal, 1936, vol. 54, Jan. 16, pp. 74–76). Particulars of the moulding and casting technique adopted when moulding air-turbine rotors in cast iron moulds are given.

High-Chromium Alloys—Centrifugal Castings and Tubes. R. J. Wilcox. (Metal Progress, 1936, vol. 29, Jan., pp. 44–48). The centrifugal casting process employed by the Michigan Steel Casting Co. for the production of high-alloy tubes is outlined. The tubes so produced are stated to be very uniform in structure, and to possess physical properties comparable with sand-cast specimens.

A Modern Machine-Tool Foundry. (Foundry Trade Journal, 1936, vol. 54, Jan. 16, pp. 65–66). An account of the foundry of Messrs. Geo. Richards and Co., Ltd., of Broadheath, near Manchester, is given. This concern manufactures machine tools. The various departments of the foundry are shortly described.

An Up-to-Date Foundry Layout. A. B. Jacobus. (Iron Age, 1936, vol. 137, Jan. 16, pp. 26–27). The foundry of E. and T. Fairbanks and Co. in St. Johnsbury, Vt., is described ; the layout and comprehensive labour-saving equipment installed are briefly indicated.

Studies on Solidification and Contraction in Steel Castings.—III. The Rate of Skin Formation. C. W. Briggs and R. A. Gezelius. (Transactions of the American Foundrymen's Association, 1935, vol. 43, pp. 274–296). The factors which influence the velocity of solidification of a steel casting, and the rate at which the skin forms are discussed. Studies were made on shapes of varying volumes, and on shapes with constant volumes but different surface areas. The numerical values obtained were used to calculate constants and formulæ of solidification. The main points which emerged were as follows : (1) The rate of skin formation increases as the volume of the steel casting decreases ; (2) the greater the surface area of a steel casting the faster is the rate of skin formation ; (3) the velocity of solidification is a constant ; that is, at any definite time after pouring the volume of steel solidified per sq. in. of mould surface is the same ; (4) variations in the moulding materials used scarcely affect the rate of solidification ; (5) the degree of superheat modifies the rate of skin formation ; (6) the rate of skin formation can be calculated for various sizes of spherical castings.

PRODUCTION OF STEEL

(Continued from pp. 124 A–127 A)

British Steelworks, No. 6—Colvilles Ltd. (British Steelmaker, 1936, Feb., pp. 11–14). The genesis, development, and present organisation of the steelworks of Messrs. Colvilles Ltd. are described.

Hawarden Bridge Steelworks of John Summers and Sons, Limited. (Iron and Coal Trades Review, 1936, vol. 132, Jan. 31, pp. 223–225; Feb. 7, pp. 268–270). A brief outline of the genesis and subsequent development of the works of Messrs. John Summers and Sons, Ltd., is followed by an account of the department in which Armco iron sheets are produced. A description of the No. 2 Steelworks is then given; this works embraces basic open-hearth melting equipment, a roughing mill, sheet mills, heating and annealing furnaces, finishing and galvanising departments and a foundry section.

The Pretoria Iron and Steel Works. (Engineer, 1936, vol. 161, Jan. 24, pp. 94–97). An account of the organisation, equipment, and productive capacity of the plant of the South African Iron and Steel Industrial Corporation, Ltd., is presented.

The Heat Losses from the Basic Bessemer Converter during a Campaign. M. Paschke and E. Peetz. (Stahl und Eisen, 1936, vol. 56, Jan. 23, pp. 86–93). The authors record their investigation of the heat losses during the campaign of a 30-ton basic Bessemer converter extending to about 300 heats. Owing to the decrease of the thickness of the lining, the final losses through the shell were about double the losses at the start. The thermal conductivity of the dolomite mass at 900° C. was determined to be 1·0 kg. cal. per m. per hr. per °C. The radiation losses through the mouth were primarily dependent on the extent of the accretions; they were reduced by 30–40% during the blow by the flame radiation. The heat losses from the body did not diminish the temperature seriously. With a short blow, the old converter worked better, because, although the heat losses were greater, the amount of ejects was less.

Use of the Venturi Port, its Design, Construction and Operation. G. L. Danforth, jun. (Iron and Steel Engineer, 1936, vol. 13, Feb., pp. 19–23). The application of the venturi port to oil-fired and gas-fired open-hearth furnaces is dealt with; suitable designs are described and illustrated.

Open-Hearth Furnaces. Factors to be Considered in Insulation. G. Soler. (Iron and Steel Engineer, 1936, vol. 13, Feb., pp. 11–13). The author considers the extent to which insulation may be applied to open-hearth furnaces and the modifications of furnace practice which should be adopted if the full benefit of insulation is to be received.

Roof Temperature Control for Use in Open-Hearth Furnaces. M. J. Bradley. (Iron and Steel Engineer, 1936, vol. 13, Feb., pp. 24–28). It is explained that in order to control the roof temperature of the open-hearth furnace it is necessary to insert a thermocouple in the roof itself, adjacent to the inside surface. The author describes the way in which the thermocouple should be installed and refers to the benefits to be derived from its use, especially in insulated furnaces.

Experiences in American Open-Hearth Steelworks. C. Schwarz. (Stahl und Eisen, 1936, vol. 56, Jan. 16, pp. 68–72). The author reviews the discussion which took place at the Eighteenth Open-Hearth Conference of the American Institute of Mining and Metallurgical Engineers, held on Apr. 11, 1935.

The Influence of Carbon on the Course of the Steelmaking Processes. F. Körber, W. Oelsen, G. Thanheiser, and P. Bardenheuer. (Stahl und Eisen, 1936, vol. 56, Feb. 13, pp. 181–201). This paper is in three sections, by Oelsen, Thanheiser, and Bardenheuer, respectively, each being based on work already published in *Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung*:

I. The Nature of the Decarburising Reaction. (*See* Körber and Oelsen, Journ. I. and S.I., 1935, No. II., p. 382).

II. The Influence of Carbon on the Metallurgical Course of the Acid Open-Hearth Process. (*See* Bardenheuer and Thanheiser, Journ. I. and S.I., 1935, No. I., p. 377).

III. The Importance of the Carbon Reaction in the Basic Open-Hearth Process. (*See* Bardenheuer and Thanheiser, Journ. I. and S.I., 1935, No. II., p. 381).

The Reactions of Chromium with Acid Slags. F. Körber and W. Oelsen. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1935, vol. 17, No. 21, pp. 231–245). The authors have investigated the reactions between chromium-bearing iron melts and chromium-bearing ferrous-oxide/manganous-oxide/silicates and solid silica. In the presence of chromium, the equilibrium reactions of iron, manganese, and silicon with their oxides in the metal layer and the slag layer were only slightly altered. The slagging of the chromium (*i.e.*, the ratio $(\Sigma\ Cr)_{slag} : [Cr]_{metal}$) was highly dependent on the composition of the steel and of the silicate slag; with rising ferrous-oxide in the slag the ratio increased very much. Higher manganese and silicon contents in the steel cause a lower ferrous-oxide content in the slag and also in the steel, and thus oppose the oxidation of the chromium. The position of chromium as a reducing agent, in comparison with iron and manganese, is discussed. Compared with manganese and silicon, chromium is only a very weak reducing agent; consequently its action during the deoxidation of chromium-bearing iron by manganese and silicon is only slight. In acid slags, and consequently also in the silicate inclusions in chromium-bearing steels, chromium, in the presence

of the other metals, occurs to only a limited extent as Cr_2O_3 and principally probably as CrO, so long as the inclusions are molten or have solidified as glasses. Not only was analytical evidence found for this, but it is even more evident in the comparatively simple equilibrium conditions of the reactions of chromium with acid slags. When the slags, and also the inclusions, crystallise, extensive breakdown of the CrO into Cr_2O_3 and metallic chromium takes place.

Calcium Silicate Slags. W. H. MacIntire, L. J. Hardin, and F. D. Oldham. (Industrial and Engineering Chemistry, 1936, vol. 28, Jan., pp. 48–57). An investigation was carried out to determine whether by-product calcium silicate slag of relatively high calcium fluoride content could be used in lieu of limestone, as a basic supplement to concentrated superphosphates. The reactivities of quenched and unquenched slags towards various media, particularly towards phosphates, were also studied.

Metals, Mattes, Slags, and Scoria, from the Point of View of Modern Chemistry. M. Rey. (Revue Universelle des Mines, 1936, vol. 12, Jan., pp. 11–20). In view of the preponderating part played by fusion processes, the mutual solubilities of molten substances in one another occupy an important position among the problems of metallurgy. Light may be thrown on this question to a certain extent by the application of modern chemical ideas and by classifying chemical compounds according to whether the bonds are atomic, molecular, or metallic in character. Neglecting all accessory phenomena which complicate the problem, the author has attempted to build up a systematic classification of the principal binary combinations. This classification—though imperfect, owing to the simplifications introduced—enables certain interesting deductions to be drawn.

A New Method for Studying the Flow Characteristics of Glasses and Slags at Elevated Temperatures. E. P. Barrett and J. A. Taylor. (Journal of the American Ceramic Society, 1936, vol. 19, Feb., pp. 39–44). An empirical method of estimating the flow characteristics of glasses and slags at elevated temperatures is described, which depends on the flow of a cast billet of the slag or glass under test when submitted to high temperatures. By the use of this technique the relative fluidity may be determined and devitrification and surface tension phenomena studied.

The Pouring of Molten Steel. J. D. Walters and E. G. Hill. (Iron and Steel Engineer, 1936, vol. 13, Feb., pp. 14–18). The various items which determine the efficiency of the teeming process (and hence the soundness of the resultant ingots) are enumerated; they include the ladles, nozzles, moulds, stools, temperature and rate of pouring, type of mould wash and hot top employed (if any), and method of stripping.

REHEATING FURNACES

(Continued from p. 58 A)

A New Bar-Heating Furnace for Sheet and Tinplate Mills. (Sheet Metal Industries, 1936, vol. 10, Feb., pp. 117–118 : Iron and Coal Trades Review, 1936, vol. 132, Feb. 7, pp. 273–274). The Gibbons-Marchant furnace in operation at the Panteg Works of Baldwins, Ltd., is described and illustrated. The furnace is 21 ft. long over the combustion chamber; a loading mechanism occupies a space of about 7 ft. and a gravity roller conveyor at the discharge end a further 16 ft., making a total overall length of 44 ft. The furnace is fired with uncleaned producer gas, and the system of firing incorporates the Gibbons-Webb roof-tile system. The roof is built up of two layers of tile, with an air space between forming a hot-air reservoir. The gas is admitted into the furnace on each side through ports at the level of the bottom roof tiles, which are perforated, and a blanket of gas is formed across the roof of the furnace. Secondary combustion air passes into the fuel beneath in the form of numerous small jets, producing a uniform sheath of flame across the furnace and in direct contact with the bars to be heated. Oxidation of the bars is impossible if the furnace is suitably regulated. On entering and leaving the furnace the bars pass under flaps, so that the reducing conditions which prevail in the furnace are not disturbed.

Acme Uses Modified " Laboratory " Slab Furnaces. (Iron Age, 1936, vol. 137, Feb. 20, pp. 38–39, 51). Illustrated particulars are given of the slab-heating furnaces at the plant of the Acme Steel Co., Riverdale Works, U.S.A. Three furnaces serve the 16-in. hot strip mill.

Continuous Pack and Pile Reheating Furnace. (Stahl und Eisen, 1936, vol. 56, Feb. 13, pp. 209–210). Very brief details of a walking-beam type of continuous reheating furnace are given.

Forging Furnaces at the Ford Plant. J. B. Nealey. (Metals and Alloys, 1935, vol. 6, Dec., pp. 351–354). The forging furnaces used for heating transmission gear blanks, rear axle gears and shafts, front spindles and bolts, and other miscellaneous parts are described.

Gas-Fired Forging Furnaces. W. G. Gude. (Steel, 1936, vol. 98, Feb. 3, pp. 48–50). **Special Methods of Gas-Firing to Avoid Scale and Soft Skin.** W. Foster. (Metal Progress, 1936, vol. 29, Jan., pp. 51–52). **Gas-Fired Furnaces for Forging Tool Steels.** (Iron Age, 1936, vol. 137, Jan. 30, pp. 32–33). An account of the performance of the gas-fired furnaces installed at the plant of the Columbia Tool Steel Co., Chicago Heights, Ill., is given. The furnaces were converted from coal to gas firing and provided with automatic combustion control; they are stated to give satisfactory results.

FORGING, STAMPING AND DRAWING

(Continued from p. 128 A)

New Plant for the Manufacture of Forged Steel Die Blocks. (Engineer, 1936, vol. 161, Feb. 28, p. 239). At the plant of Thos. Firth and John Brown, Ltd., Sheffield, new equipment is in operation for the rapid production of small and medium-sized forged steel die blocks. It consists of a 5-ton steam hammer, a gas-fired reheating furnace, a normalising and hardening furnace, a tempering furnace, an oil-quenching tank, and the necessary auxiliary equipment. The types of steels used for the manufacture of die blocks, together with particulars of the composition and treatment, are shown.

Van Stoning and Bending Pipe. J. B. Nealey. (Iron Age, 1936, vol. 137, Feb. 6, pp. 34–36, 95). The operations of "van stoning" (forming end flanges by forging) and bending pipes at the St. Louis plant of the Midwest Piping and Supply Co. are described. The main features of the plant are the gas-fired furnaces for heating the pipes, the flanging machine, and the bending and cutting appliances.

The Plastic Working of Metals. G. Sachs. (Metal Industry, 1936, vol. 48, Jan. 17, pp. 51–54). Recent advances in theoretical knowledge of the plastic working of metals are reviewed. Attention is given to strain-hardening, the influence of speed on hot- and cold-working, crystal orientation, tool design, and the process of deformation.

Press Accidents are Reduced by Safety in Die Design. R. A. Shaw. (Steel, 1936, vol. 98, Feb. 17, p. 38). Practical hints concerning the ways in which press accidents may be reduced are given.

Wire and Wire Drawing. A. T. Adam. (Metal Treatment, 1935, vol. 1, Winter issue, pp. 172–178). The present state of knowledge on this subject is reviewed. Attention is given to wire steels, the cold flow of metals in the wire-drawing operation (and particularly the work of Herbert and Thompson in this field), the heat treatment of wire rod and the nature of the constituents present, pickling, wire-drawing, and the mechanical properties of wire. In connection with this last the relations between the carbon content, the heat treatment, and the reduction by drawing are discussed; brief mention is also made of the tests and service requirements applicable to cold-drawn wire.

ROLLING-MILL PRACTICE

(Continued from pp. 129 A–132 A)

Experiences with the "Pasopos" Roll Pressure Tester. W. Lueg and A. Pomp. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1935, vol. 17, No. 19, pp. 213–218). The "Pasopos" roll-pressure tester measures the displacement of the lowest point of the lower roll body which occurs during rolling; a small roller, attached to one arm of a lever, rolls on the roll body, and the other end of the lever transmits its movements through a diaphragm capsule and tubing to the recording apparatus. Tests on the appliance showed that the movements of the feeler roller were magnified ninety times by the recorder. Experiments on a number of rolling mills showed that there was a fixed relation between the indications of the recorder and the sum of the bearing pressures measured simultaneously with a hydraulic-pressure gauge. Flexure of rolls of which the ratio of the length to the diameter of the roll body was slightly greater than unity could not be measured in these tests.

The Pasopos Roll-Pressure Indicator and Recorder. (Sheet Metal Industries, 1936, vol. 10, Jan., p. 20).

The Broken Hill Proprietary Company, Limited, Combination Merchant and Skelp Mill and 12-in. Mill. W. J. Todhunter and C. B. Kirkhouse. (Proceedings of the Australasian Institute of Mining and Metallurgy, 1935, No. 99, Sept. 30, pp. 357–373). After describing the original mill put down at Newcastle, New South Wales, Australia, in 1917, the authors give an account of the modifications subsequently introduced and of the new equipment installed in 1933 for the manufacture of skelp and light sections. The main features of the present mill comprise the original 18-in. continuous mill for rolling billets and slabs, a gas-fired billet reheating furnace, and an 8-in. continuous mill with roughing, intermediate, and finishing sections. The old 12-in. mill formerly used has been retained for use on miscellaneous orders. The mill is capable of producing rounds, squares, light sections and rails, narrow flats, skelp and strip, at the rate of over 3000 tons a week.

The Influence of the Material of the Rolls, the Speed of Rolling, the Strip Width and Previous Cold Deformation on the Cold-Rolling of Strip Steel. W. Lueg and A. Pomp. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1935, vol. 17, No. 20, pp. 219–230). Cold-rolling tests were made on three low-carbon steels, the roll pressure, the cross-section of the strip before and after each pass, and the speed gain being measured; the material was in all cases lubricated with oil emulsion. Provided that the surface finish of the rolls was equally good, it was found that the material

of the rolls had no effect on the rolling process. With hardened and polished chromium-steel rolls, no influence of the speed of rolling for variations of the rate of rotation of the rolls in the ratio of 1 : 130 could be observed. The influence of the cross-section of the material was examined by rolling strips of the same material and similarly pretreated but of different widths; hardened and polished chromium-steel rolls rotating at about 10 r.p.m. were used. For equal reductions of thickness the roll pressure increased linearly with the strip width. For small reductions, the average resistance to deformation increased with the strip width, at first rapidly and then more slowly; for larger reductions, giving numerically larger values for the deformation resistance, the effect was less marked; when the ratio of the breadth to the thickness exceeded about 15, the effect disappeared. The speed gain was similarly affected by the strip width. With all degrees of reduction, the maximum spread occurred with a ratio of width to thickness of 5–7·5; with the ratio greater than 22·5 (approx.) the influence of the width on the spread ceased. To determine the influence of the condition of the material, strips were cold-rolled to varying degrees before the experimental rolling (the same rolls and lubrication were used as before). For equal reductions, the roll pressure and resistance to deformation increased with the prior cold-work, at first rapidly and then more slowly; with reductions of 20% and above and the more severe degrees of cold-working, a steeper increase in these values set in, the commencement of the increase occurring at lower degrees of cold-work as the reduction increased. The speed gain was affected similarly. These effects are attributed to the earlier and more marked flattening of the roll surfaces at the pressure point consequent on the increasing hardness of the material rolled. The extent of the prior cold-work was practically without effect on the spread. Tensile tests on the material after rolling showed, as expected, an increase in the tensile strength with increasing reduction and with increasing cold-work, while the elongation decreased correspondingly.

Tube Making in Australia. A. N. Hamilton. (Proceedings of the Australasian Institute of Mining and Metallurgy, 1936, No. 99, Sept. 30, pp. 375–442). The author describes the system of producing butt-welded tubes by the bell and continuous (Fretz-Moon) processes, details the method of forming sockets and screwed ends at some length, and finally summarises the salient features of the Fretz-Moon process.

Output Supervision in a Tube Rolling Mill by Weighing. J. Schröck. (Stahl und Eisen, 1936, vol. 56, Feb. 27, pp. 269–270). A short note on the supervision of the output in a tube mill in such a way that the rapidity of output is not interfered with.

A New Method for Welding Together Ferrous Metals by Application of Heat and Pressure. L. C. Grimshaw. (American Institute of Mining and Metallurgical Engineers, 1936, Technical Publication No. 667; Metals Technology, 1936, vol. 3, No. 1, Jan.). An account

is given of the Armstrong process for the production of composite steel billets by forging or rolling. The bond between the two metals comprising the billet is formed by electrolytic iron deposited on the surfaces to be united. During heating diffusion occurs between the electrolytic iron and the basis metal, and forging or rolling produces a perfect weld free from oxide. Where there is a great difference in hot-work ductility between the two metals comprising the billet, special rolls and guides must be used to guard against flow of the more ductile metal around the less ductile one. The various shapes and positions of insert material that can be produced in the finished material are shown.

Electrolytic Iron Provides Bond in Cladding with Special Alloys. R. R. Rogers. (Steel, 1936, vol. 98, Feb. 10, pp. 34–35). The Armstrong method of producing composite billets is described.

Individual Motor Drives for Runout Tables and Coiler Rolls. W. B. Snyder and L. E. Hildebrand. (Iron and Steel Engineer, 1935, vol. 12, Dec., pp. 16–23). The author analyses the factors which govern the selection and method of operation of individual motor drives for runout tables, coilers, and similar applications. The types of motors available, the methods of operation, the accelerating and decelerating losses, torque requirements and heating limitations, motor speed and frequency, and control equipment are examined in turn.

High-Speed Fly-Wheel for Rolling Mill. (Engineer, 1935, vol. 160, Dec. 20, pp. 654–655). A description of a 41-ton flywheel built for the new works of the British (Guest Keen Baldwins) Iron and Steel Co., Ltd., is given. The flywheel is designed to take the peak load as the ingot enters the rolling mill. The wheel is 11 ft. 6 in. india., rotates at 600 r.p.m. and has a stored energy of 200,000 h.p. sec.

HEAT TREATMENT

(Continued from pp. 133 A–136 A)

Influence of Alloy Additions on the Scaling of Iron. E. Scheil and K. Kiwit. (Archiv für das Eisenhüttenwesen, 1936, vol. 9, Feb., pp. 405–416). (*See* p. 66 A.)

Experiments on the Loss by Burning in Rolling-Mill Furnaces. Second Part.—Analysis of the Magnitude of the Factors. (The Influence of the Furnace Atmosphere.) F. Strähuber. (Stahl und Eisen, 1936, vol. 56, Jan. 30, pp. 108–113). In the first instalment, the author was concerned with the influence of the time factor on the scaling loss in reheating furnaces (*see* p. 24 A). In the present section, he deals with the effect of an oxidising atmosphere under conditions of approximately constant discharge temperature and length of time in the discharge section of the furnace, the influence of a prolonged stay in the discharge hearth under various atmospheres, and the dependence of the scaling loss on the discharge temperature and on the extent of the excess or deficiency of air in the discharge hearth. Under an oxidising atmosphere the scaling is greater than under reducing conditions, but the magnitude of the excess or deficiency of air is without influence. Prolonged stay of entire groups of ingots in the discharge hearth, particularly in an oxidising atmosphere, leads to increased scaling; doubling the time raises the scaling loss by nearly one-half. The influence of the discharge temperature is very great; an increase from 1300° to 1400° C. increases the loss by 170%. By arranging the average scaling losses of the ingot groups investigated in accordance with the atmospheres that existed in the discharge hearth, the very great effect of the discharge temperature, the waiting period in the discharge hearth, and the length of time at temperatures above 900° C. can be seen. These influences can exceed that of the furnace atmosphere to such an extent that, for equal heating times, the scaling loss under an atmosphere with a deficiency of air may be greater than that under an atmosphere containing an excess of air.

Steels for the User—XV. Heat Treatment of High-Carbon Steel. R. T. Rolfe. (Iron and Steel Industry, 1936, vol. 9, Jan., pp. 157–160). An account of the composition, mechanical properties, and heat treatment of steel for needles and instrument pivots is given.

The Effects of Heat Treatment on Carbon Steels. E. Widdowson. (Machinery, 1936, vol. 47, Feb. 6, pp. 557–560). The author gives an account of the effects of heat-treating carbon steels, and of the nature of the constituents which appear.

Cause and Avoidance of Cracks in Heat-Treated Steel. J. C. Oliver, W. N. Barrows, and R. J. Williams. (Steel Treatment Society, Australia, June 25, 1935: Heat Treating and Forging,

1935, vol. 21, Nov., pp. 525–530; Dec., pp. 581–583). The subject is dealt with under the following headings: (1) Selection of the steel, (2) design, (3) heat treatment, (4) grinding and finishing, and (5) service failure. The bearing which each of these has on the problem of cracking is indicated, and the heat-treating technique to be followed if cracking is to be avoided is outlined.

Influence of Heat Treatment between A_1 and A_3 on the Structure and Impact Notch Toughness of Low-Carbon Steel. E. Dobinsky and H. Hanemann. (Archiv für das Eisenhüttenwesen, 1936, vol. 9, Jan., pp. 359–366). By annealing treatments at temperatures between the A_1 and A_3 points, the notch toughness of low-carbon steel can be improved above the values attainable by normalisation. This improvement is the result of the disintegration or dispersion of the pearlite. Determination of the individual effects of the grain size and the pearlite form on the notch toughness showed that this property was dependent only on the form and distribution of the pearlite in the structure. In specimens with high notch-toughness characteristics the fracture commenced at the root of the notch, but in specimens of medium or low toughness the fracture started in the deeper layers below the root of the notch.

Annealing Sheet and Strip Steel with the Use of Electric Furnaces. A. N. Otis. (Iron and Steel Engineer, 1936, vol. 13, Feb., pp. 1–9). The salient characteristics of electric annealing furnaces of the continuous, bell, and box type are compared and some of the results obtainable with each type of furnace are reproduced.

Electric Furnaces to Bright Anneal High-Carbon Stock. W. Roth. (Metal Progress, 1936, vol. 29, Jan., pp. 35–38). The advantages of atmosphere-controlled electric furnaces for bright annealing high-carbon steel stock are cited, and the performance of this type of furnace is compared with that of the type formerly employed.

Influence of the Rate of Running Through in the Lead Patenting of Steel Wire on the Strength Properties of the Drawn Wire. A. Pomp and H. Ruppik. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1935, vol. 17, No. 23, pp. 259–274). A 0·66% carbon steel wire was patented with various quenching and lead-bath temperatures and with three different speeds of passage through the bath. The time during which the wire remained at a temperature above A_3 (determined by the speed and furnace temperature and length) was measured by a thermocouple welded to the wire. The results show that a change in the rate of passage has a marked influence on the properties of the wire in their relation to the quenching and bath temperatures. The most suitable conditions for patenting and draughts in drawing for the attainment of the best properties in the wire, particularly the flexibility and torsion number, are indicated. The authors have also sought for a meaning of a maximum in the torsion number observed after medium draughts in drawing the wire.

WELDING AND CUTTING

(Continued from pp. 137 A–139 A)

Permanency of Oxy-Acetylene Welding. F. C. Huchison. (International Acetylene Association, 1935: Welding Industry, 1936, vol. 4, Feb., pp. 10–12). Examples of the great durability of gas-welded pipe lines exposed to a variety of conditions, including corrosion and mechanical damage, are cited.

Arc Welding in Argon Gas. G. E. Doan and W. C. Schulte. (Journal of the American Welding Society, 1936, vol. 15, Jan., pp. 23–27). (*See* p. 73 A.)

Arc-Welding Apparatus. E. Steinert and W. W. Reddie. (Iron and Steel Engineer, 1936, vol. 13, Jan., pp. 9–12). Modern developments in A.C. arc-welding apparatus are briefly reviewed.

Present Position of Welding Technique in Mining in the Ruhr. K. Baatz. (Glückauf, 1936, vol. 72, Jan. 18, pp. 62–67). The appliances available at mines in the Ruhr for making gas and electric welds are reviewed, and examples of the use of welding on various items of plant, principally in repair work, are given.

The Correct Repair of Grey Iron Castings by Gas Fusion-Welding with Cast Iron. H. Reininger. (Giesserei, 1936, vol. 23, Jan. 31, pp. 52–57). In this review of the practical details of which care must be taken in the gas-welding of grey-iron castings, the author shows that this welding method is an adequate means of effecting satisfactory repairs and correcting all kinds of casting defects, gives information regarding the correct pretreatment of the object to be welded, as usually given in practice, and describes the actual welding process, the filler rods and fluxes used, and the results obtained.

The Welding of the Alloy Steels. J. C. Hodge. (Journal of the American Welding Society, 1936, vol. 15, Jan., pp. 6–14). The author discusses the chief alloy steels suitable for welding, with respect to their structure, composition, strength, and weldability. The low-alloy structural steels, low-, high-, and medium-chromium steels, chromium and nickel-chromium stainless steels are among those considered.

Welding and Cutting High Chromium Steels. W. J. Priestley. (International Acetylene Association, Nov., 1935: Journal of the American Welding Society, 1936, vol. 15, Jan., pp. 14–17). Notes on the technique of welding and cutting steels containing upwards of 4% of chromium are furnished; the value of titanium- and columbium-bearing steels in improving the weldability is emphasised.

Tests to Determine the Feasibility of Welding the Steel Frames of Buildings for Complete Continuity. W. M. Wilson. (Journal of the American Welding Society, 1936, vol. 15, Jan., pp. 28–38). A detailed account of some full-scale tests on welded structures to

determine the efficiency of welded beam-to-girder and girder-to-column connections is presented. Both static and reversed-load tests were undertaken; the results are presented in tabular and graphical form.

Mechanised Forge Welding of Tanks. J. B. Nealey. (Steel, 1936, vol. 98, Feb. 10, pp. 30–33). The Columbiana Boiler Co., Columbiana, O., manufactures pressure vessels, tanks and containers by the forge-welding process, the heating agent employed being natural gas converted (by steam) to blue water gas. The author explains the procedure adopted in fabricating these vessels.

Inspection of Welded Seams in Pressure Vessels. W. D. Halsey. (Journal of the American Welding Society, 1936, vol. 15, Jan., pp. 20–23). A method of inspecting the welded seams of pressure vessels is described, in which plugs of metal are removed by trepanning with a small cylindrical saw. The trepanning tool enables the specimens to be removed for examination. Examples of the application of this method are cited.

Yoloy—Its Properties and Welding. F. J. Esslinger. (Journal of the American Welding Society, 1936, vol. 15, Jan., pp. 18–19). The welding properties of Yoloy (a low-carbon steel containing small amounts of phosphorus, copper and nickel) are set forth. Some test results obtained on welded specimens are cited.

Elasticity Conditions in Welded Joints and their Tensile Fatigue Strength. E. Diepschlag, A. Matting, and G. Oldenburg. (Archiv für das Eisenhüttenwesen, 1936, vol. 9, Jan., pp. 341–345). Tensile fatigue tests have been carried out on V, X, and fillet arc and gas-fusion welds made in test-pieces of steels of various compositions. In all cases it was found that the greater the difference between the elastic deformability of the parent metal and of the weld the lower was the fatigue strength of the joint. There are two ways of ensuring adequate tensile fatigue strength in a welded joint: (1) The elastic deformability of the weld metal is made as nearly as possible equal to that of the parent metal, so that the shear stresses and stress peaks, set up by variations in the transverse contraction, remain low under the tensile stressing; (2) the shear stresses are distributed over a larger amount of metal by laying the weld obliquely. For this purpose also a gentle transition from weld to parent metal should be aimed at by melting deeply.

Study of the Fatigue Resistance of Flush Welds. H. Dutilleul. (Génie Civil, 1936, vol. 108, Jan. 18, pp. 62–64). The author describes the fatigue testing method (rotating cantilever) used, the manner in which the flush welds were made and the preparation of the fatigue specimens, and presents the results in the form of a diagram; he concludes by discussing the causes which may reduce the fatigue resistance of welds in relation to that of the sound parent metal. The steel used for making the specimens had a tensile strength of 50 kg. per sq. mm. (composition not stated), and the welds were made by the electric arc with various electrodes.

CLEANING AND PICKLING OF METALS

(Continued from p. 81 A)

Preparation of Metal Surfaces for Painting. F. Kappler. (Zeitschrift des Vereines deutscher Ingenieure, 1936, vol. 80, Feb. 15, pp. 183–185). Metal surfaces were cleaned by brushing, by pickling and by sand-blasting, and were then coated with a variety of paints to determine the influence of the cleanliness of the metal surface on the adhesion and life of the paint. The author concludes that brushing is adequate for ordinary structural parts, but that for highly stressed structures (bridges, &c.) sand-blasting should be used; pickling is suitable only for single articles and where subsequent cold-deformation is in question, and on no account should it be used for built-up articles, because of the penetration of the acid into the joints.

Economical Method of Descaling Forgings. (Heat Treating and Forging, 1936, vol. 21, Dec., pp. 577–580). An account of the construction, operation, and performance of the Wheelabrator Tum-Blast machine, in which a tumbling motion is combined with the abrasive action of the Wheelabrator impeller stream, is given. The machine described is that installed at the plant of the Moore Drop Forging Company, Springfield, Mass., for the descaling of forgings.

Pickling of Steel Sheets and Strip. (Sheet Metal Industries, 1936, vol. 10, February, pp. 123–124). Particulars are given of the pickling machine for the pickling of coiled steel strip at the works of the Whitehead Iron and Steel Co., Ltd., Newport, and the four-vat sheet pickling machine in operation at the works of John Lysaght, Ltd., Newport.

Conveyors applied to Strip Mill Pickling Operations. J. H. Hough. (Iron Age, 1936, vol. 137, Feb. 20, pp. 34–36). The author discusses briefly equipment such as roller tables, coil up-enders, and tilting mechanisms used in continuous pickling plants. The layout of the conveying system used in the strip pickling plant of a large American steelworks is illustrated.

COATING OF METALS

(Continued from pp. 37 A–38 A)

Study of the Throwing Power of Electrolytic Baths. A. Portevin and M. Cymboliste. (Académie des Sciences, Oct. 28, 1935: Génie Civil, 1935, vol. 107, Nov. 30, pp. 532–534). A short account is given of experiments in which the throwing power of various electrolytes, and the influence of various factors on it, were determined. The specimens were dihedral in shape and the distribution of the electrodeposited coating was determined by weighing.

Control of Electroplating. (Steel, 1936, Jan. 27, pp. 37–38; Feb. 3, pp. 43–44, 69; Feb. 10, pp. 36–38; Feb. 17, pp. 44–45). In the first instalment in this series the relationships between the weight of electrodeposited coatings and their thickness are set forth, and a recommended test for porosity is described; the second and third are concerned with the quantitative determination of the nickel, copper, chromium, zinc, and tin in electrodeposited coatings, while in the final instalment the method of estimating the silver and gold in coatings of precious metal is described, together with a second porosity test.

The Trend of Recent Developments in Electrodeposited Coatings. A. W. Hothersall. (Metal Industry, 1936, vol. 48, Jan. 17, pp. 115–120). The trend of recent developments in the application of metallic coatings by electrodeposition, and in the control of the properties of the deposits is indicated. It is shown that improvements in the control of adhesion, and of the protective quality of electrodeposits, have been taking place, so that it is now possible to formulate specifications for deposited coatings.

Brilliant Metallic Deposits. M. Schlötter. (Zeitschrift für Metallkunde, 1935, vol. 27, Oct., pp. 236–237). Electrolytically-deposited metals are not absolutely pure. The nature of the metal deposit, in regard to the grain-size and rate of growth, is influenced by the anions present in the electrolyte; increasing molecular volume decreases the rate of growth and favours the number of nuclei formed. Under particular conditions of electrolysis, compounds of the deposited metal with anions (halides, oxides, hydroxides, sulphides, &c.) may be incorporated in the lattice structure; as a result, the physical and chemical properties of the deposited metal are altered.

Electrodeposition of Chromium for Wear Resistance. J. Kronsbein. (Electrodepositors' Technical Society: Metal Industry, 1936, vol. 48, Feb., pp. 193–194). An account of the technique to be used in chromium-plating gauges and other parts which are required to resist wear is given.

Nickel-Plating and Chromium-Plating—Progress and Present Position. M. Ballay. (Seventh International Congress on Mining,

Metallurgy and Applied Geology, Paris, Oct. 20–26, 1935, Metallurgical Section, vol. 1, pp. 77–83).

The Problem of the Electrolytic Precipitation of Fe–Ni Alloys.—II. F. Marschak, D. Stepanow, and L. Lewins. (Zeitschrift für Elektrochemie, 1935, vol. 41, pp. 596–597). The authors have made experiments to determine the influence of the current density (0·5–15 amp. per sq. dm.), the temperature (18°, 40°, 70°) and the combined concentration of the iron and nickel ions on the electrodeposition of iron-nickel alloys. It was found that the ratio of the concentrations of the iron and nickel ions to one another in the solution and the current density had a considerable influence on the composition of the resulting deposit, but that the temperature and total concentration of the two ions were of secondary importance.

Imperfections in Electrodeposits. A. Chaybany. (Metal Industry, 1935, vol. 47, Oct. 25, pp. 423–426). On the basis of the hypothesis that pinholes and pores in cobalt deposits are due to the presence of colloidal particles, experiments on electrodeposited cobalt coatings were performed. The pure double sulphate with ammonia was prepared and used for the plating solution. Excellent pore-free deposits were obtained. When a less pure solution was employed, however, pores were produced. Arsenic was suspected of provoking this trouble, and tests confirmed the fact that arsenic, in all but very small concentrations, exerts a bad effect.

Rust-Proofing by Cromodine Process. (Iron Age, 1935, vol. 136, Oct. 31, pp. 34, 76). In the Cromodine process the parts, prior to being painted, are dipped in (or sprayed with) a solution of Cromodine for 1 min. at 180–190° F. This coats the surface with a thin film of iron chromate which is said to cause the surface to become self-polarised, so preventing rust. Salt-spray and weathering tests show that articles treated with Cromodine before being painted retain their adhesion, lustre, and freedom from rust much better than do untreated specimens. The process is claimed to be suitable for rust-proofing almost any type of steel product, and particularly cold-rolled material.

New Information on the Lustre Shading of Metals. G. Gross. (Zeitschrift für Metallkunde, 1935, vol. 27, Oct., pp. 238–241). After touching on the older methods of applying lustre shades to metals, the author describes improvements that have been effected in order to avoid the earlier difficulties. The solution given in the literature consists of sodium thiosulphate and lead acetate dissolved in water. By varying the proportion of the salts, ageing the bath, and adding cream of tartar, the speed of action of the bath is increased and the temperature required is lowered from nearly boiling to room temperature. The colour produced on iron is steel blue.

Recent Calorising Research. J. B. Nealey. (Heat Treating and Forging, 1935, vol. 21, Oct., pp. 483–484).

Longer Life for Galvanising Furnaces. W. G. Imhoff. (Machinist, 1936, vol. 80, Feb. 1, pp. 18–20). It is pointed out that the

following three main influences are those which serve to shorten the life of galvanising pots: External corrosion by the products of combustion; internal attack by zinc dross and flux; and mechanical pounding. They are shortly discussed in turn.

Corrosion after Pickling Major Source of Galvaniser's Dross. W. G. Imhoff. (Iron Age, vol. 136, Dec. 5, pp. 30–33, 116–118). Dross from the galvanising process may be attributed to the following sources: (1) The zinc used, (2) iron oxides formed on the surface of the work after pickling, (3) iron salts in the pickling solutions, (4) iron from the galvanising pot, (5) iron from the articles treated, and (6) iron furnished by material lost in the pot. The author deals with the second source (iron oxides on the surface of the work), and discusses the way in which the contaminating oxides are formed. The initial corrosion products which occur are the sulphates or chlorides of iron (sulphuric acid giving rise to the former, and hydrochloric acid to the latter), and brown iron oxide or "sull." Experiments were performed in which iron oxide and zinc were melted together at various temperatures. Molten zinc was observed to have a decided reducing action on the iron oxide, forming zinc oxide and zinc-iron alloy at 850° F. At higher temperatures (950° F., for instance) zinc is absent and the melt consists of zinc-iron alloy of a spongy nature, and crystals of dross; the iron oxide has almost disappeared. Above 900° F., the tendency to form dross is strong; at 1300° F. the melt consists entirely of dross and zinc-alloy crystals. From this evidence it is concluded that the molten zinc reduces the iron oxide to iron; the latter forms zinc-iron alloy, and the oxygen reacts to give zinc oxide; the iron so introduced increases the hardness of the zinc. The nature of the products depends largely on the temperature—the reducing action of the zinc increases as the temperature is raised. A chemical analysis of the melts revealed that at 800° F. there was 0·99% of iron in the melt, at 850° F. there was 3·03%, and at 900° F. there was 3·70%. This latter figure corresponds with that actually found in galvanising baths, thus confirming the experimental investigations.

The Reactions of Iron with Molten Zinc. W. Püngel, E. Scheil, and R. Stenkhoff. (Archiv für das Eisenhüttenwesen, 1935, vol. 9, Dec., pp. 301–304). The attack on iron by molten zinc can take place in two ways, according to whether crystals of $FeZn_3$ are formed or not. If $FeZn_3$ is not produced, the attack is very heavy; in this case a porous skeleton of $FeZn_7$ is formed, so that the zinc is continuously in contact with the iron, and dissolves and combines with it. The resulting alloy layer grows at right angles to the surface of the iron and gives rise to remarkable shapes. The non-formation of $FeZn_3$ is observed only up to a definite upper temperature limit. The formation of this iron-zinc compound produces a dense impermeable protective layer, which stops the attack on the iron by the zinc. The observations are as yet insufficient to give information regarding the connection between

the composition of the steel or the zinc bath and the formation of $FeZn_3$.

The Tinplate Trade in 1935. W. R. Brown. (Iron and Coal Trades Review, 1936, vol. 132, Jan. 17, pp. 136–137). The author presents a survey of the changes in the manufacture of sheets and strip for tinplate which have taken place during recent years, and indicates the trends which are likely to continue. These include the production of wide or narrow strip by the continuous mill or Steckel mill and the adoption of fully mechanised mills.

Acceptance of Tinplate as a Raw Material for Box and Can Manufacture. (Sheet Metal Industries, 1936, vol. 10, Feb., pp. 137–138). The inspection methods available at box-making and can-making works are discussed. The four tests in general use are as follows: Tin-yield and steel substance, Jenkins bend test, cupping test and the porosity test.

Influence of the Working Conditions during Tinplating on the Porosity of Tinplate. F. Peter and G. Le Gal. (Archiv für das Eisenhüttenwesen, 1935, vol. 9, Dec., pp. 285–287). The porosity of tinplate cannot be attributed to any single factor. It is dependent primarily on the surface cleanness of the untinned sheet, on the thickness of the tin coating, and also on the pickling process, the purity of the flux, &c. According to experimental results, hydrogen, absorbed by the sheet during manufacture and particularly during pickling, and given off again in part in the tin pot, does not play the preponderating part in the production of pores in the tin coating that has been ascribed to it. Further, it was found that in the modern usual tin coatings on commercial tinplate freedom from porosity cannot be attained despite all precautions. Only with coatings of about 100 g. per sq. m. can pore-free tinplate be produced, and only then when every means is adopted to reduce porosity.

Electrolytic Tinplating. M. Cymboliste. (Chimie et Industrie, 1935, vol. 34, Dec., pp. 1270–1278). The author presents a summary review of the deposition of tin coatings on metals by the hot-dip process and by the electrolysis of either fused salts or of electrolytes, particular attention being paid to alkaline electrolytes.

The Mellozing Metal Spraying Process. (Engineering, 1935, vol. 140, Dec. 27, p. 704). In the Mellozing process, developed by Messrs. Mellowes and Co., Ltd., Sheffield, molten metal is sprayed by means of compressed air on to steel, wood, glass, or other surfaces. The alloy or metal to be sprayed is first melted in a gas-fired crucible. It is then poured into a container forming part of the pistol, and is maintained in the molten state by a Bunsen-type burner which also preheats the compressed air. The latter issues from a nozzle conveying the liquid metal, by means of an annular space. When in use the pistol is tilted slightly downwards, so that the metal flows to the nozzle by gravity, where it is atomised and projected at a high velocity on to the parts to be treated. Iron and steel surfaces

should be sand-blasted before being coated, but this is not necessary with soft materials. In normal operation the pistol is held 6 in. from the work, and the thickness of the coating is 0·004 in. with one application, the speed of working being from 8 to 10 sq. ft. per min. The pistol consumes compressed air at the rate of 15 cu. ft. of free air per min. and town gas at the rate of 50 cu. ft. per hr. The process is successfully used for spraying zinc, tin, aluminium, and certain alloys, and has numerous industrial applications.

Laboratory Control in Dry-Process Enamelling. R. D. Cooke. (Bulletin of the American Ceramic Society, 1935, vol. 14, Nov., pp. 373–374). A description is given of the methods used for controlling the raw materials, and mixing, melting, and applying dry-process enamels for cast-iron sanitary ware.

The Preparation of Iron Castings for Vitreous Enamelling by Sand Blasting. F. W. Wilson. (Institute of Vitreous Enamellers : Foundry Trade Journal, 1936, vol. 54, Jan. 2, pp. 7–8). The use of the sand blast in the vitreous enamelling industry is treated under the following headings : (1) Types of plant used ; (2) abrasives ; (3) air pressures ; (4) nozzles ; and (5) operating troubles.

Effect of Mill Practice and Mill Additions on the Opacity of Enamels. G. L. Bryant and F. R. Porter. (Journal of the American Ceramic Society, 1936, vol. 19, Feb., pp. 55–59). The results are presented of work on improving the opacity of enamels by mill practice and mill additions, such as milling to an abnormal degree of fineness, the addition of opacifiers at the end of the milling period, the effect of the addition of felspar, and the effect of different types of clays.

Effect of Clays on the Opacity of White Enamel for Sheet Steel. R. R. Danielson. (Journal of the American Ceramic Society, 1936, vol. 19, Feb., pp. 59–61). A study of the effect of different clays on the opacity of white enamels was made. Different clays were found to give rise to differences in reflectance of as much as 5%. It is suggested that where suspension and opacity are both important a blend of clays may be used to impart these qualities.

How Colouring Oxides are Affected by Variations of Enamel Composition. W. Ball. (Institute of Vitreous Enamellers, Foundry Trade Journal, 1936, vol. 54, Feb. 6, pp. 125–126). The author discusses the stability of colouring oxides, the colour variation difficulties met with, and the types of enamel suitable for carrying the colouring oxides.

How the Continuous Enamelling Furnace Affects Copperheads. H. L. Cook. (Bulletin of the American Ceramic Society, 1935, vol. 14, Dec., pp. 393–395). Possible reasons are given for the more frequent appearance of copperheads on enamels fired in continuous furnaces than in box furnaces, and suggested operations for the better preparation of metal for enamelling are discussed.

Common Defects in the Vitreous Enamelling of Sheet Iron, C.R.C.A. Steel and Cast Iron. C. P. Stone. (Institute of Vitreous

Enamellers, Sept. 28, 1935: Sheet Metal Industries, 1935, vol. 9, Oct., pp. 633–636, 642).

Eliminating the Blistering of Enamels on Cast Iron. H. D. McLaren. (Canadian Ceramic Society, Feb. 26, 1935: Steel, 1935, vol. 97, Dec. 30, pp. 25, 40). It is pointed out that susceptibility to blistering depends, among other things, on the type of micro-chill (or hard surface skin) produced on castings. The hard skin contains a higher percentage of combined carbon than the body of the casting, and during firing this is set free in the finely divided and readily oxidisable state; the resulting formation of carbon dioxide and carbon monoxide gives rise to blisters. The analysis of the cast iron should be controlled so as to produce either a fairly soft micro-chill, which can be readily removed by sand-blasting, or a stable structure which does not break down on heating. Suitable analyses are reproduced. Other causes of blistering briefly referred to are the use of carbonaceous facings, the presence of excess moisture, and unsoundness in the castings.

Notes on Draining of Ground-Coat Enamels for Sheet Steel. M. C. Gautsch. (Bulletin of the American Ceramic Society, 1936, vol. 15, Jan., pp. 14–15). Some observations of the effect of atmospheric conditions and other factors on the draining behaviour of ground coats are given.

Enamel Thickness Gauge. M. A. Rusher. (Bulletin of the American Ceramic Society, 1935, vol. 14, Nov., pp. 365–367). The methods generally available for gauging the thickness of an enamel or other coating on steel usually necessitate puncturing of the surface coating. An instrument for the non-destructive testing of enamel thicknesses has been devised. It is electrically operated, and consists of a gauge head and an indicating unit, designed for a 110-V. 60-cycle lighting circuit. In principle it depends on the magnetic reluctance of the enamel under the gauge head. The gauge head consists of an electromagnet with a central pole and annular return pole; it is energised by the electric supply through a metal rectifier. When the head is placed on an enamelled sheet the magnetic circuit is completed by the latter, and the reluctance of the interposed film of air or enamel is measured by an indicator. It is adjusted for different thicknesses of sheet steel by means of a balancing coil. The use of the gauge is not confined to enamel coatings; it may be equally well applied to other non-magnetic materials such as glass, mica, and celluloid. An example of the use of the gauge in determining enamel thicknesses is furnished.

Minimum Radius of Curvature for Enamelled Parts. H. H. Holscher. (Bulletin of the American Ceramic Society, 1935, vol. 14, Nov., pp. 369–371). Sharp edges are a fruitful source of trouble in enamelling. By suitable design control, however, it should be possible to send material through the enamelling process without resort to reinforcement or patching. To determine the minimum

radius for enamelled parts four series of eleven panels of 20-gauge iron with two bent edges were enamelled, and the condition of the enamel at various stages was determined by visual inspection. It is concluded that if firing-off of the ground coat on the bent edge is admissible, and when no cover enamel is applied, the radius may be as small as it is possible to produce with the gauge of metal used. If the bent edge must be perfectly covered the radius should be not less than $\frac{9}{64}$ in. Firing-off of the ground coat becomes very serious when the radius is less than $\frac{1}{8}$ in.

A Method for Testing the Adherence of Ground Coats to Metal. C. J. Kinzie and J. B. Miller. (Bulletin of the American Ceramic Society, 1935, vol. 14, Nov., pp. 371–373). Essentially the apparatus consists of a hand-operated press equipped with a plunger, a steel ball, and two cast-iron plates for holding the specimen and guiding the plunger and ball. The specimen panel is clamped between the cast-iron plates, and pressure is put on the plunger; the metal is deformed by the ball, and on inspecting the panel for degree of adherence an estimate may be made of the quality of the enamel in this respect. The test is a modification of the familiar Erichsen cupping test, and is said to be useful for control and development purposes.

Japanning Costs Reduced by Drying. J. B. Nealey. (Iron Age, 1935, vol. 136, Dec. 5, pp. 34–36). In the japanning section of the works of the Graham Paige Motors Corp., Detroit, the work to be treated is first washed, rinsed, and dried in a single oven through which the parts are carried on a conveyor. On emerging, the parts are dried by gas-fired torches held by hand; this removes the last traces of moisture and any dirt present. The parts are then conveyed to the japanning tanks and finally stoved in gas-fired ovens at 490° F.

The Painting of Metals. (Metals and Alloys, 1935, vol. 6, Dec., pp. 361–364). Five papers on the painting of metal surfaces, presented to the Paint and Varnish Division of the American Chemical Society in April, 1935, are summarised and discussed. Among the aspects dealt with are the causes and mechanism of corrosion, and the preparation of iron and steel for painting; the painting of non-ferrous metals is also considered.

Some Problems of Protection against Rust. A. V. Blom. (Korrosion und Metallschutz, 1935, vol. 11, Nov., pp. 245–249). A brief discussion of the nature of corrosion, protective films and coatings, the preparation of the metal surface for coating (painting) and the properties of films (paint coats). Some rules regarding the prevention of the rusting of iron by means of paint are appended.

Securing Paint Adhesion on "Difficult" Metals. (Sheet Metal Industries, 1936, vol. 10, Feb., 151–152). Brief particulars are given of the "Lithoform" and the "Granodine" processes for the precoating of galvanised steel and cadmium-plated metals in order to render them paint receptive.

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Rust-Proofing and Paint Adherence. F. P. Spruance. (Society of Automotive Engineers: Automobile Engineer, 1936, vol. 26, Jan., pp. 41–42). The principal methods adopted for improving the paint adherence and rust resistance of metal finishes are outlined. The following reagents and processes are briefly described: Cleaning with a phosphoric acid and oil-solvent mixture (Deoxidine); the Dip-Bonderite process, which uses a solution of manganese dihydrogen phosphate and copper phosphate; Spra-Bonderite, a modification of the last process; electro-Granodising (using zinc phosphate and an alternating current); zinc Granodising, used for zinc-plated surfaces; Lithorising; the oxalate process; and the Cromodine process.

A Test for the Water-Resisting Properties of Paints for Steelwork. L. P. McHatton. (Journal of the Institution of Petroleum Technologists, 1935, vol. 21, Dec., pp. 989–991). A method of testing the water-resisting properties of paint is outlined, in which a painted metal plaque was made one side of a rectangular cell containing salt water or other electrolyte, the plaque constituting one electrode and a rod of carbon being used as the other. Arrangements were made to bubble air through the electrolyte. The resistances of the cells, and the potentials developed, were measured initially and after 24 hr. on short circuit. Figures relating to tests on red-lead/red-oxide, red lead, white lead, synthetic resin and cement glue are reproduced. The author remarks that in some cases breakdown of the paint film was confined to isolated spots or pinholes, and he describes a method of detecting such invisible defects. This depends on the deposition of iodine from potassium iodide on the application of an electric potential, and consequent staining of a starch solution if pinholes are present. The author observes that a fall in the electrical resistance of the film points to an increase in porosity; hence the electrical resistance should be an indication of the weathering properties of the paint. Figures for boiled linseed oil and copal varnish, with or without tung oil additions, are reproduced.

PROPERTIES AND TESTS

(Continued from pp. 140 A–146 A)

The Relation between the Tension Static and Dynamic Tests. H. C. Mann. (Proceedings of the American Society for Testing Materials, 1935, vol. 35, Part II., pp. 323–335). From the earliest investigations of this subject, attempts have been made to correlate impact results with some physical characteristic of the static tension test, but without definite results. In practically all these investigations, however, a wide variety of shapes and sizes of notched specimens was used, and since each gave a new series of impressions as to the interpretation of the results obtained, advancement to a thorough understanding of the true significance of the impact test was greatly retarded. From the use of a tension form of specimen which could be tested under both static and dynamic conditions, data have been obtained which have led to the discovery of a correlation between these two types of tests. This correlation involves consideration of the fact that a material in its initial state possesses a certain amount of inherent internal potential energy, which, during the process of deformation, is apparently converted to kinetic energy and manifested as increased elastic strength. Data are presented regarding this internal energy factor which clearly indicate that the mechanism of the process of deformation and rupture is essentially the same under both static and dynamic conditions. It is also shown that since time is required for energy conversions to take place, the total energy value obtained must be dependent on the force, time, and space, and therefore to obtain a complete knowledge of the dynamic properties of materials, the velocity of the force application must be considered.

Research on Yield Limits and the Tensile Strength of Mild Steel and other Metals. G. Welter. (Metallurgia, 1936, vol. 13, Jan., pp. 89–92). (*See* p. 83 A.).

Influence of Cold-Work and Ageing on the Behaviour of Steel under Alternating Stress. F. Körber and M. Hempel. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1935, vol. 17, No. 22, pp. 247–257). The effect of the mechanical and thermal ageing of cold-worked steels on the static properties, the bending and tension-compression fatigue strength, the changes in the damping capacity of the material, and metallographic and X-ray tests are reported on. A 5 or 10% cold deformation without ageing reduces the notch toughness considerably; thermal ageing decreases it still further. For both steels tested (carbon 0·02% and 0·39%) and for both degrees of cold-work, the notch toughness of the mechanically aged specimens (by stress alternations) approximated to the value for the cold-worked unaged specimens. This suggests

that the effects of the thermal and mechanical ageing of cold-worked steels arise from different causes. The influence of the two ageing treatments, after different degrees of cold-working, on the tensile strength, yield point and fatigue strength of the two steels was not the same; for both degrees of cold-work, there was no difference between the values of these properties of the mechanically aged and thermally aged specimens of the 0·02% carbon steel; in the case of the 0·39% carbon steel, the properties after mechanical and thermal ageing were the same for 5% cold-work, but after 10% cold-work thermal ageing was superior to mechanical ageing. In the damping measurements, the dependence of the damping on the amplitude, time and deformation was determined. For both materials the stable damping of the 5% cold-worked and thermally aged specimens was less than that of those aged mechanically; after 10% cold-work the condition was reversed. No alteration of structure due to tensile-compressive stressing could be observed. By the X-ray reflection method, the change of the width of the interference lines due to cold-working, and also before and after tensile-compressive stressing, was examined. The line width increased with the cold-work (no alternating stressing). For the 5% cold-worked specimens aged by either method, there was no clear indication of any change in the line width with and without alternating stressing, but with the 10% cold-worked specimens, both unaged and thermally aged, the sharpness of the lines increased after alternating stressing.

Measurement of Circumferential Forces by Means of a Carbon Pressure-Measuring Capsule. W. Lueg. (Zeitschrift des Vereines deutscher Ingenieure, 1936, vol. 80, Jan. 11, pp. 47–49). The measuring capsule works on the principle that the electrical resistance of a pile of carbon discs varies as the pressure with which the discs are pressed together is altered. It is fitted into a special form of coupling introduced between the driving mechanism and the driven machine. Three examples of the type of curve obtained are given, showing the variation of the torsional moment during the rolling of strip steel, and the influence on its magnitude of the surface condition of the material being rolled.

Determination of Torsional Stresses from Measurements of Extension. J. Crumbiegel. (Zeitschrift des Vereines deutscher Ingenieure, 1936, vol. 80, Jan. 25, pp. 101–102). For the condition of pure shear stress, a simple relation between stress and extension has been developed, by means of which torsional stresses may be calculated direct from extension measurements. Tests on a tube of circular section confirm the accuracy of the relation. Experiments with a square tube revealed a stress distribution differing considerably from the parabolic form expected, the maximum value of which was overestimated by nearly 17% by the usual method of calculation.

Defects Due to Improper Working of Steel. E. W. Nelson. (Heat Treating and Forging, 1935, vol. 21, Dec., pp. 563–565).

Some of the defects associated with incorrectly hot- or cold-worked steel—such as cracking, banding and burning—are discussed.

Notes on the Carrying Out of Fatigue Tests. W. Späth. (Metallwirtschaft, 1936, vol. 15, Jan. 24, pp. 91–93). In the Wöhler method of fatigue testing, numerous specimens are stressed under decreasing loads until finally one remains unbroken after a very large number of stress cycles. In the alternative method, a single specimen is subjected to a load below the expected fatigue limit; if the specimen withstands a million stress reversals without failure, the load is increased and the test continued, until finally the test-piece fractures. The latter method gives fatigue limits greater than those found by the Wöhler method, and the author's purpose is to determine which values are "correct." By means of a "model" specimen built of springs, he shows that constancy of the applied-load conditions by no means assures that the internal stress conditions shall remain constant during the whole course of the fatigue test; further, the results of the test must vary according to whether the test is carried out under constant load conditions or constant deformation. He then applies these considerations to the two methods of testing; in the Wöhler test two opposing influences are at work, one tending to diminish and the other to raise the fatigue resistance, but in the increasing-load method the conditions are straight-forward. Internal stressing and the course of damping are brought into relation with one another; the more rapidly an initial internal overstress vanishes, that is, the more quickly the externally measurable damping reaches its limiting value, the earlier will the conditions determining the occurrence of a fracture be set up. The raising of the fatigue strength of certain steels by artificial pretreatment is suggested; static as well as dynamic loading can be used for this purpose.

Are Fractures of Automobile Back Axles Fatigue Fractures? M. Ulrich. (Zeitschrift des Vereines deutscher Ingenieure, 1936, vol. 80, Feb. 15, pp. 181–182). The author presents the results of tests intended to explain the sector-shape of the fracture in splined shafts; these show that these failures are not fatigue fractures.

Permanent Magnet Materials. C. S. Williams. (Electrical Engineering, 1936, vol. 55, Jan., pp. 19–23). The magnetic and physical properties and the relative costs of the following classes of material, namely, nickel-aluminium-iron, cobalt-molybdenum-iron, and cobalt-tungsten-iron alloys, and the mixed oxides of cobalt and iron, are compared.

Nickel-Copper-Iron Alloys and their Magnetic Properties. (Metallurgist, 1936, Feb., pp. 104–107). This is a summary of recent work by German investigators on the constitution, and magnetic and physical properties of nickel-copper-iron alloys.

Hydrogen as a Cause of Reduced Elongation and Reduction of Area of Steel. C. Drescher and R. Schäfer. (Archiv für das Eisenhüttenwesen, 1936, vol. 9, Jan., pp. 327–331). Tests made on a basic open-hearth steel (carbon 0·16%, silicon 0·9%, manganese

0·99%, phosphorus 0·042%, sulphur 0·04%, copper 0·38%), killed with aluminium, which, after rolling to a variety of sections, gave unsatisfactory elongation and reduction-of-area values, showed that these properties could be much improved by heating for various periods at various temperatures. Further, the fractured surface of the test-pieces, which was spongy and full of small white flakes in the untreated condition, became free from flakes and of the usual conical shape after treatment. Means were not available for the direct determination of the hydrogen content of the metal, but from these tests, and others which were designed to show that other factors could not have had any influence, the authors conclude that in certain circumstances hydrogen can cause the appearance of white flakes in the fractured surface of tensile test-pieces, and that the latter are the reason for the reduced elongation and reduction-of-area values.

Nitrogen Content and Structural Abnormality of Sintered-Carbonyl Steels. H. Cornelius and H. Esser. (Archiv für das Eisenhüttenwesen, 1936, vol. 9, Jan., pp. 367–368). It is shown that iron carbonyl contains relatively large quantities of nitrogen. This probably is explained by the fact that the finely-divided powder produced when the carbonyl is decomposed absorbs nitrogen, especially when ammonia is added to the iron-carbonyl vapour in the preparation of low-carbon iron. As the nitrogen in sintered-carbonyl steel is without effect on the A_1 transformation and the tendency to structural abnormality, determinations showing the relationship between the degree of purity of sintered-carbonyl steels and the form of the A_1 transformation on the one hand, and their abnormal structural development on the other, must be regarded as valid.

The Properties of Genuine Cold-Blast Pig-Irons. J. E. Hurst. (Foundry Trade Journal, 1936, vol. 54, Jan. 30, pp. 99–100). Notes on the properties of cold-blast pig-irons—especially the resistance to hammer fracture compared with other irons—are presented.

Cast Iron for the Manufacture of Glass Bottle Moulds. N. L. Evans, W. Goacher, and J. E. Hurst. (Journal of the Society of Glass Technology, 1936, vol. 20, Feb., pp. 45–53). The authors discuss a number of factors governing the choice of materials for making glass bottle moulds. The moulds considered are the "parison" mould and the "blow" mould as used in the automatic production of glass containers, but the data on suitable irons for moulding are applicable to all moulds used in the glass industry. It is suggested that a suitable specification for pig iron for glass bottle moulds would be one in which the percentage composition was as follows :

Total Carbon . .	3·1% (maximum)
Silicon . . .	According to thickness of casting.
Sulphur . . .	0·07% (maximum)
Phosphorus . .	0·45% (maximum)
Manganese . .	0·8–1·5%

A chart showing how the silicon content should vary in relation to the prevailing thickness of the casting is given.

The Manufacture of Moulds for Steel Ingots. J. Leonard. (Technical Association of Metallurgy of Charleroi : Pamphlet issued by A/S Bremanger Kraftselskab, Bergen). After pointing out that the failure of ingot moulds may be attributed on the one hand to deterioration of the mould surface, and on the other to the development of fissures, the author gives an account of a dilatometric study of the growth of cast iron and its effect on the deterioration of ingot moulds. In this connection the formation of graphite from Fe_3C, the influence of particle size, and the effects of the presence of oxygen in cast iron are mentioned.

" Ni-Hard " Rolls in Strip Mill Service. (Sheet Metal Industries, 1936, vol. 10, Feb., pp. 121–122). The applications of " Ni-Hard " cast iron for rolls in both hot- and cold-rolling mills are briefly discussed.

Recent Studies in Cast Iron. (Metal Treatment, 1935, vol. 1, Winter Issue, pp. 206–209). This article is an abridged translation of an article by Jungbluth and Heller which appeared in Stahl und Eisen, 1935, vol. 55, Nov. 21, pp. 1241–1243.

Special Cast Irons. A. Le Thomas and M. Ballay. (Seventh International Congress on Mining, Metallurgy and Applied Geology, Paris, Oct. 20–26, 1935, Metallurgical Section, vol. 1, pp. 267–280 : Revue de Métallurgie, Mémoires, 1936, vol. 33, Jan., pp. 24–37). After discussing the effects of various alloying elements on the properties of cast iron, the authors review the properties and applications of the special cast irons in general industrial use.

Silicon Cast Irons. L. Guillet, jun. (Chaleur et Industrie, 1936, vol. 17, Jan., pp. 14–15). A very short note on the properties of silicon cast irons.

Bibliography of Literature on the Effect of Aluminium in Cast Iron. (Bulletin of the British Cast Iron Research Association, 1936, vol. 4, Jan., pp. 264–271). This bibliography consists of fifty-one references to the literature on the effect of aluminium in cast iron and covers the period 1888–1935. No text-book or patent literature is included.

Stainless Steels. H. Bull. (Royal Aeronautical Society, Dec. 12, 1935 : Welding Industry, 1936, vol. 4, Feb., pp. 20–23). The author gives a brief outline of the development of stainless steels, discusses the problem of weld decay and its prevention, and touches on the more recent advances in the production of stainless steels.

Development of Stainless Steels. W. H. Hatfield. (Ironmonger, 1936, vol. 203, Jan. 11, pp. 96–97). A brief account of the development and application of stainless steels is furnished.

What the Sheet-Metal Worker should Know about Stainless Steel. T. Swinden. (Sheet Metal Industries, 1936, vol. 10, Feb., pp. 148–150, 171).

The Evolution and Progress of Rust-, Acid-, and Heat-Resisting Steels. W. H. Hatfield. (Iron and Coal Trades Review, 1936, vol. 132, Jan. 17, pp. 134–136). An account of some of the applications of chromium, and nickel-chromium steels of the rust-, acid-, and heat-resisting types is furnished.

Note on the Corrosion-Resisting Steels and their Uses. F. Croset. (Arts et Métiers, 1936, vol. 89, Feb., pp. 30–33). A general discussion of the mechanical properties of chromium and nickel-chromium rustless steels and the uses to which they may be put.

Heat-Resisting Chromium Cast Irons. P. Bastien. (Chaleur et Industrie, 1936, vol. 17, Jan., pp. 13–14). A short note on the influence of chromium on cast iron and the properties of chromium cast irons.

Metallic Materials for Heat Exchangers. A. Portevin. (Chaleur et Industrie, 1936, vol. 17, Jan., pp. 11–13). A short discussion of the mechanical and other properties of metals to be used in the construction of heat exchangers and the use of steel and cast iron for this purpose.

The Deterioration of Colliery Winding Ropes in Service. S. M. Dixon, M. A. Hogan, and S. L. Roberton. (Mines Department, Safety in Mines Research Board, 1936, Paper No. 94). The Wire Ropes Committee of the Safety in Mines Research Board has been conducting investigations into the gradual deterioration of wire ropes in service and the conditions at the point of fracture of ropes broken in service. The present paper covers the work of the Committee on this subject up to the present time, and incorporates the more important features of an earlier paper published in 1928 (Paper No. 50). The results presented show definitely that corrosion-fatigue is the chief cause of rope deterioration. The results of observations and tests on nearly 250 winding ropes, 85 of which had broken in service, are summarised. Other sections of the paper deal with the production and properties of the wire used in winding ropes, the various types of winding ropes and their manufacture, and the effect of different factors in the winding conditions on the endurance of the rope.

Influence of Various Factors on the Life of Mine Haulage Ropes. H. Herbst. (Seventh International Congress on Mining, Metallurgy and Applied Geology, Paris, 1935 : Revue de l'Industrie Minérale, Mémoires, 1936, No. 362, Jan. 15, pp. 27–37). The author discusses the influence of the various factors (mechanical properties and dimensions of the wires, galvanising, construction of the rope, &c.) which affect the life of mine haulage ropes on the basis of statistical research on the results obtained with actual ropes in practice and the results of laboratory tests; both the practical and the laboratory results were obtained in Germany.

The Problem of Retirement of Wire Rope from Service. B. M. Suslov. (Wire and Wire Products, 1936, vol. 11, Jan., pp. 19–21, 48). Some results of researches by Woernle on the deterioration of

wire ropes are presented. Endless ropes of Lang-lay and ordinary lay, and of different types of construction, were made to travel (under a specified tension) over sheaves; after a certain period the tests were interrupted and the ropes tested for breaking strength. Lang-lay ropes of Seale construction were found to behave best. The investigation shows that the ordinary breaking-load test is not a sufficient criterion of the durability and reliability of ropes in service; a fatigue test, such as that described, is needed.

The Selection of Mould Steel. J. C. Alexander. (Machinery (Lond.), 1936, vol. 47, Jan. 16, pp. 469–470). After enumerating the characteristics desired in moulds for powdered products, the author arranges the available materials in the following order of merit: High-carbon, high-chromium steel; low-tungsten, low-chromium steel; manganese-chromium steel; nickel-chromium steel; carbon tool steel; stainless steel; mild steel and soft iron. The hardening, machining, and other properties of each steel are discussed.

Cost and Performance Data on Forged and Detachable Bits. (Engineering and Mining Journal, 1936, vol. 137, Jan., pp. 23–26, 30). A study of the behaviour of forged and detachable drilling bits under service conditions is presented. The tests took place at Norris Dam quarry, near Knoxville, Tennessee; under the conditions met with the detachable bits were found to give the most satisfactory service.

Casting and Welding. G. Meyersberg. (Montanistische Rundschau, 1936, vol. 28, Stahlbau-Technik, Jan., pp. 6–7). The relative merits of castings and welded components for structural work are compared. Earlier comparisons, based on ordinary cast iron, have favoured welded construction, but in modern high-duty cast irons the properties have been much improved. Pattern-making costs militate against cast iron when only single or very few articles of a kind are required. The author concludes that for rigidity, security of seating, maximum avoidance of vibration, and resistance to distortion, cast iron should be chosen; while welding gives a very light form of construction, much can be done to lighten castings by taking advantage of the thin sections that are possible with the high-duty irons of to-day.

CORROSION OF IRON AND STEEL

(Continued from p. 150 A)

The Structure of Thin Films of Metallic Oxides and Hydrates. N. Smith. (Journal of the American Chemical Society, 1936, vol. 58, Jan., pp. 173–179). The structures of thin films of metallic oxides, hydroxides, and hydrates, prepared in various manners, were investigated by the method of electron diffraction. The oxide films removed from metals were found to be polycrystalline, consisting of relatively large crystals of the normal metallic oxides, without preferred orientation or pseudomorphism. The films consist of only a few layers—perhaps only a single layer—of crystals. Films of hydroxides and hydrates were crystalline, but the crystals were quite small, and showed evidence of lattice distortion.

Inhibitors—Safe and Dangerous. U. R. Evans. (Electrochemical Society, April 1936, Preprint 69–1). An attempt to inhibit the anodic reaction of a corrosion change controlled by the cathodic reactions will usually diminish the corroded area more quickly than it diminishes the total destruction of metal, and thus increase the intensity of corrosion if the addition has been insufficient to stop attack altogether; such methods of inhibition are dangerous. This intensification of attack will not occur where the corrosion is under anodic control, or where the inhibitor is one which smothers the cathodic reaction. These principles are applied in discussing the addition of alkali to hard, soft, and saline waters, and also the treatment of brine with chromate. The classification of protective processes into safe and dangerous groups can be extended to protection by oxide-films, paints, and metallic coats.

Comparison between the Effect of Hydrogen-ion Concentration on the Rate of Corrosion of Steel in Pure Oxygen and Air at 25° C. J. M. Bryan. (Transactions of the Faraday Society, 1935, vol. 31, Dec., pp. 1714–1718). In general, steel corrodes more readily with a rough than with a relatively smoother surface, because the rougher surface encourages the hydrogen-evolution type of corrosion. In the absence of air the rougher surface stimulates corrosion over the *p*H range 2·4–5·5. In the presence of a limited supply of air, the effect is negligible at *p*H 2·4, but increases progressively with decreasing acidity to *p*H 5·5.

Pure oxygen and ferric iron are very similar in their action towards steel, since they both strongly inhibit the evolution of hydrogen at high acidity, and greatly stimulate the oxidation type of corrosion at low acidity (*p*H 5·0–5·5). With air, on the other hand, the inhibition is only slight at high acidity, and there is an actual stimulation of the hydrogen-evolution type of corrosion at low acidity. This stimulation is, however, only an initial effect, and

there seems little doubt that it is arrested by an accumulation of dissolved iron, which would tend to prevent free oxygen from reaching the metal. The cause of the stimulation by a low concentration of oxygen is not clear, but it is possible that other factors, such as film formation, have a bearing on the problem. The fact that corrosion is stimulated at low acidity by air and, to a larger extent, by pure oxygen, indicates that the controlling factor in the absence of oxygen is not the rate of deposition of hydrogen-ions, but some other factor, probably the overvoltage of hydrogen. Hydrogen-ion concentration appears to be a factor of little importance over the *p*H-range when pure oxygen is present, and the rate of corrosion seems to be controlled mainly by either the rate of diffusion of oxygen or its reaction with hydrogen at the surface of the metal. When air is present, the volumes of hydrogen depolarised are also much the same over the *p*H-range unless appreciable amounts of dissolved iron are present, but in the case where the concentration of oxygen is low, a considerable amount of hydrogen escapes oxidation, and is evolved as a gas.

Hydrogen-ion concentration is an important factor in influencing the rate at which dissolved iron oxidises or is reduced. A reduction in hydrogen-ion concentration promotes the oxidation of ferrous iron by oxygen to the ferric condition, whereas an increase favours the reverse process, *viz.*, the reduction of ferric iron during the evolution of hydrogen. Ferrous iron, by acting as an oxygen-carrier in the presence of air, promotes the oxidation-type of corrosion over the whole *p*H-range; its activity is greatest at about *p*H 4. This process becomes increasingly important as corrosion proceeds.

Specimens corroded above and below *p*H 4 show a marked contrast in their appearance when air is present. This is of particular interest, since it provides visible evidence for the transition at *p*H 4·3, noted by other workers, between the hydrogen-evolution and the oxidation types of corrosion. The phenomenon is not observed in the absence of oxygen, but the transition is induced by its presence, even in small traces.

Effect of Mixed Acids upon Irons and Steels. J. Eddy and F. A. Rohrman. (Industrial and Engineering Chemistry, 1936, vol. 28, Jan., pp. 30–31). A study was made of the passivifying effect of mixtures of sulphuric and nitric acids on various types of steel. High-carbon steels were found to show a greater tendency to retain their passivity than low-carbon steels. Tests with dilute mixed-acid solutions revealed that for each steel a critical dilution existed at which the steel lost its passivity and became attacked. Samples high in manganese and sulphur were seen to have a lower passivity than specimens low in these elements. The general effect of alloying elements, however, was to improve the passivity. Quenched steels showed a greater tendency to resist mixed acids than furnace-cooled steels.

Study on the Passivity of Iron and Steel in Nitric Acid Solution. Report VIII. Y. Yamamoto. (Scientific Papers of the Institute of Physical and Chemical Research (Japan), 1936, vol. 28, Jan., abstracts, pp. 1–2). The influence of nitrates added to concentrated nitric acid on the passivity of iron was studied. The nitrates used (copper nitrate excepted) augmented the passivity and lowered the critical concentration; $AgNO_3$ was particularly effective. The phenomenon appears to be related to a rise in the valency of the metal and the production of nitrous acid.

Action of Solutions of Sodium Silicate and Sodium Hydroxide at 250° C. on Steel under Stress. W. C. Schroeder and A. A. Berk. (American Institute of Mining and Metallurgical Engineers, 1936, Technical Publication No. 691; Metals Technology, 1936, vol. 3, No. 1, Dec.). The authors report the results of some experiments on the action of sodium silicate and sodium hydroxide on steel under stress. Tubular specimens of boiler steel, ground on the test length or provided with an eccentric groove, were enclosed in a bomb containing the caustic fluid at a temperature of 250° C., and stressed in this condition. The authors conclude that at 250° C. concentrations of NaOH up to 25 or 50 g. per 100 g. of water do not produce any significant effect on the strength of boiler steel. Additions of small amounts of sodium silicate, however, greatly reduce the tensile strength. On specimens subjected to both tension and bending, the load that could be carried was reduced from 65,000 lb. per sq. in. in water to less than 20,000 lb. per sq. in. in NaOH–Na_2SiO_3 solutions. Microscopic examination of the specimens indicated that in the presence of sodium silicate fine intercrystalline cracks were produced near the fracture.

The Corrosion Problem in Steel. A. McCance. (Institution of Engineers and Shipbuilders in Scotland, Preprint, Feb. 25, 1936). After referring to the mechanism of rusting and the part played by dissolved oxygen in the fundamental chemical reactions which take place, the author proceeds to consider the effect of the chemical composition of the steel, the corrosion resistance of copper steels, the influence which the oxygen supply has upon the rate of corrosion, and the effects of differential concentration and aeration upon the process of rusting. He then discusses the formation of protective films, the effect of mill scale on the resistance to corrosion, and, finally, the degree of protection afforded by painting.

The Influence of Corrosion-Fatigue on Mine Haulage Ropes. S. M. Dixon and M. A. Hogan. (Seventh International Congress on Mining, Metallurgy and Applied Geology, Paris, 1935: Revue de l'Industrie Minérale, Mémoires, 1936, No. 362, Jan. 15, pp. 21–26). The authors discuss the fatigue resistance and the corrosion-fatigue resistance of cold-drawn steel wires, the breakage of haulage cables owing to corrosion-fatigue, slow fracture, and the prevention of corrosion-fatigue. (See p. 200 A.)

Researches Relating to the Work of the French Commission on the Corrosion of Metallurgical Products of Interest in Aeronautics. Grard, R. Legendre and R. Lecœuvre. (Seventh International Congress on Mining, Metallurgy and Applied Geology, Paris, 1935, Metallurgical Section, vol. 1, pp. 399–409). A review of the principles which have guided the Commission in the conception, arrangement and carrying-out of their work, with a list of researches undertaken up to 1934, and some brief notes by various investigators on work on corrosion which they have done.

On the Resistance of Nitrided Austenitic Manganese Steel Against Sea-Water Corrosion. S. Satoh. (Scientific Papers of the Institute of Physical and Chemical Research (Japan), 1936, vol. 28, Jan., pp. 221–230). The single potential differences of nitrided special steels were measured in sea-water against a standard calomel electrode, and the corrosion resistance was estimated on this basis. Nitralloy containing nickel gave low negative potentials and resisted attack well, but austenitic manganese steel nitrided for 60 hr. actually gave a positive potential and was therefore noble; it was quite stainless. The changes in hardness and microstructure were also studied.

The Corrosion of Tinplate. T. P. Hoar. (Technical Publications of the International Tin Research and Development Council, 1936, Series A, No. 30). The corrosion of tin and steel, alone and as a galvanic couple, is outlined, more particularly with respect to the electrochemical behaviour of the metals under the influence of corrosive media. Some general cases of tinplate corrosion in service are then considered, and certain remedial measures for the prevention of tinplate corrosion are discussed.

Report of the Director of Food Investigations for the Year 1934. Section VI.—Canning. (H.M. Stationery Office). Among the studies included in the above section are the following: The corrosion of tin (by citric acid in the presence of sodium chloride, and of sucrose); the effect of various inorganic substances on the corrosion of mild steel by citric acid at about *p*H 3·5; the corrosion of steel and tinplate by actual extracts of fruits; and the diffusion of hydrogen through mild steel sheet and tinplate.

The Resistance of Galvanised Iron to Corrosion by Domestic Water Supplies. S. C. Britton. (Journal of the Society of Chemical Industry, 1936, vol. 55, Jan. 24, pp. 19T–22T). Experiments on the resistance of galvanised iron to normal corrosive media (tap waters) were conducted. In waters with a *p*H value between 7·5 and 9·5 and containing calcium carbonate, but of low salinity, the attack on the zinc was soon stifled, but that on the iron continued. Waters low in calcium carbonate, or containing appreciable quantities of salts, gave rise to pitting on the zinc, although on the iron the corrosion was more even. This is due to the fact that in the case of zinc an insoluble carbonate layer forms which is partly protective; in the case of iron the corresponding product becomes

removed from the surface. The electrochemical protection appears to depend on the thickness of the zinc layer, the calcium carbonate content, the *p*H value and the conductivity of the water.

The Corrosion of Screwed Joints at Raised Temperatures till they are Rusted-In. H. Vollbrecht. (Archiv für das Eisenhüttenwesen, 1936, vol. 9, Feb., pp. 397–404). On high-pressure vessels, such as are used in the chemical industry, the screws by which the end covers are held in place are usually found, after a certain period, to be so firmly fixed that they cannot be moved without breaking them. On cutting out these fixed joints, shearing and crushing of the thread can be observed at one or more points. The contact surfaces of the nut and washer are roughened. It has been found that this fixture by rusting is dependent on the duration and temperature of heating. The positions of the spots that become rusted solid indicate no regularity, but it would seem that the lowest, most heavily stressed part of the thread suffers most rapidly. In the author's investigation of this fixing of screwed joints by corrosion, plain steel, heat-resistant Cr–Mo, austenitic Cr–Ni, and nitrided Cr–Al–Mo steels, screwed together, were used; in other tests the influence of the temperature on the thickness of the oxide layer formed by heating to various temperatures, and the effect of surface oxidation on the frictional conditions, were determined. Temperatures of up to 500° C. were used. The tests on screwed joints showed that the tendency to rust solid decreased as the difference in surface hardness between the nut and bolt diminished, also as the thickness of the oxide layer decreased for nuts and bolts of similar metals. The limiting thickness of oxide layer, below which no locking occurred, was found to be 150 $\mu\mu$. When the hardnesses of the nut and bolt were different, the surface compression had no influence on the locking. With oxide layers more than 150 $\mu\mu$ thick, the surface pressure for nuts and bolts of similar metals should not exceed the tensile strength of the oxide.

Strength Properties and Behaviour towards Corrosion of Structural Steels. E. Maurer and H. Heine. (Archiv für das Eisenhüttenwesen, 1936, vol. 9, Jan., pp. 347–357). The tensile properties, bending fatigue strength (smooth and notched specimens) in air and under water spray, resistance to weathering, ageing, heat-treatability and brittleness at low temperatures of a number of structural and bridge steels of German and American origin were determined and compared. No difference in the suitability of the German steels for structural purposes or for use in normal machine construction was observed, and it is concluded that the modern scrap-carburisation method of making steel can produce a material the equal in every way of steel made by the pig-and-scrap process.

ORES—MINING AND TREATMENT

(Continued from p. 115 A)

The Preparation of Iron Ores. P. Henry. (Seventh International Congress on Mining, Metallurgy, and Applied Geology, Paris, Oct. 20–26, 1935, Mining Section, vol. 1, pp. 248–256). A general discussion of the processes of preparation and pretreatment to which iron ores may be subjected before charging into the blast-furnace.

Ore-Sintering Plant at Corby. (Iron and Coal Trades Review, 1936, vol. 132, Feb. 28, p. 402). A short illustrated account of the Dwight-Lloyd sintering plant installed at the Corby Works of Messrs. Stewarts and Lloyds, Ltd., is given.

Ore-Handling, Crushing, and Sintering Plant at the Staveley Coal and Iron Company's Devonshire Works. (Iron and Coal Trades Review, 1936, vol. 132, Feb. 21, pp. 350–357). An illustrated account of the ore-handling, crushing, and sintering equipment installed at the above works is given.

Porosity, Reducibility, and Size Preparation of Iron Ores. T. L. Joseph. (American Institute of Mining and Metallurgical Engineers, 1936, Technical Publication No. 688; Metals Technology, 1936, vol. 3, Feb.). Samples of iron ores widely differing in porosity were reduced with hydrogen under a prescribed set of conditions. The reducibility, expressed as the reciprocal of the time required for 90% reduction, varied directly with the porosity. The relation developed indicated the degree of crushing for ores within certain ranges of porosity.

FUEL

(Continued from pp. 164 A–168 A)

Modern High-Pressure Boilers and their Design Problems. A. L. Mellanby. (Journal of the West of Scotland Iron and Steel Institute, 1936, vol. 43, Jan., pp. 59–66). Modern developments in the design of high-pressure boilers, and the problems which arise from their use, are considered. Attention is given to the conditions of heat transmission, the strength of the materials employed, and to boilers of the Velox and Loeffler type.

British Coals, their Analyses and Uses. (Fuel Economist, 1936, vol. 11, Feb., pp. 201–202). A further collection of analyses and characteristic thermal data of British coals. (*See* p. 43 A.)

Study of the Coals of the North Belgian Coal Basin. M. Legraye. (Revue Universelle des Mines, 1936, vol. 12, Feb., pp. 49–59). After reviewing briefly the situation, extent, stratigraphy, tectonics, and present development of the coal basin of La Campine, the author describes the principal characteristics of the fuels mined there. On the basis of numerous analyses of coals from seams being worked, he indicates the manner in which the content of volatile matter varies throughout the deposits and discusses the cause of it.

Study of Coals from the Saar Basin. R. Chandesris. (Revue de l'Industrie Minérale, Mémoires, 1936, No. 361, Jan. 1, pp. 1–20; No. 365, Mar. 1, pp. 243–278). The Saar coals are classed into three groups; of these, only one, the fat coals, is used for coke-making, and of this group, while some coals will make good coke, others yield only an inferior product. The author set himself to solve the following problems: Why do not all the coals of the one group produce equally good coke, and how can the line of demarcation between the fat coking coals and the other non-coking varieties be determined? In the first part the author discusses the experimental methods available and indicates those which he used; in the second he records his results, and discusses what conclusions can be drawn.

Recent Installation of a Coal Washery in a Large American Mine. F. Galand. (Revue Universelle des Mines, 1936, vol. 12, Feb., pp. 66–68). Some particulars are given of a coal washery, built by the Koppers Rheolaveur Co., at the Fidelity pit of the United Electric Coal Co. in Illinois, U.S.A. (*see also* Coal Age, May 1935).

Investigation of Procedure for Determination of Coal Grindability by the Ball-Mill Method. S. G. Black. (American Institute of Mining and Metallurgical Engineers, 1936, Contribution No. 95). The author presents data obtained from an investigation conducted

on the grindability of coal by the ball-mill method. The data presented tend to show that this method might give results that are misleading, and that a volume measure might be more indicative of the true grindability of materials of varying specific gravity.

Further Investigation of Methods for Estimating the Grindability of Coal. H. F. Yancey and M. R. Geer. (American Institute of Mining and Metallurgical Engineers, 1936, Contribution No. 94). The authors present results of an investigation of the grindability of coal by the ball-mill method, and this method is compared with the C.I.T. roll test and the Hardgrove machine method.

Some Characteristic Properties of Coking Coals. H. Koopmans and H. A. J. Pieters. (Fuel in Science and Practice, 1936, vol. 15, Feb., pp. 40–42). The authors have determined the coking properties of samples of vitrain subjected to a uniform rate of heating. Curves relating the swelling properties, plasticity and rate of decomposition to the softening temperatures are plotted.

Measurement of the Swelling Properties of Coal. (Fuel in Science and Practice, 1936, vol. 15, Feb., pp. 36–39). A new form of apparatus has been devised which is suitable for measuring the swelling properties of coals. It works on the dilatometer principle, and consists essentially of a tube of heat-resisting steel closed by a cap at one end and containing the sample of coal in the form of a cylindrical briquette. A loaded piston slides within the tube and exerts a force on the swelling coal, the movement of which is recorded on a drum. Two such tubes, together with a pyrometer and the bulb of the thermostatic control, are contained in a vertical tubular gas-heated furnace, and tests may be carried out in duplicate. Suitable modifications permit the apparatus to be used for low- or high-temperature carbonisation.

The Carbonisation of Vitrains and their Mixtures. H. A. J. Pieters, H. Koopmans, and J. Hovers. (Fuel in Science and Practice, 1936, vol. 15, Feb., pp. 43–47). Samples of crushed vitrain were pressed into briquettes and heated to the desired carbonising temperature at the rate of 2° C. per min., under a pressure of 1 kg. per sq. cm. and in an inert atmosphere. The carbonised briquettes were crushed, and the particles above 1 sq. mm. mesh were mixed with bakelite resin and briquetted under heat and pressure. The specimens were split, polished, etched, and examined. The structures of the carbonised specimens are illustrated and described. Determinations of the plasticity were also carried out; the results are given in graphical form.

Methods for the Works Supervision of the Reactivity of Coke. G. Speckhardt. (Glückauf, 1936, vol. 72, Mar. 7, pp. 225–231). From a critical consideration of the methods in use to-day for determining the reactivity of coke, it appears that only those in which commercial lump coke is used can give comparative figures of value in practice. On this basis methods have been worked out for determining the properties of coke in practice using the minimum

amount of coke or even none at all. Experiments carried out in this connection have led to the establishment of the concept "practical" reactivity. Up to 1000° C. it is influenced by the "specific" reactivity, but at higher temperatures the latter assumes a constant value which is the same for all types of coke. Hence, having once determined the "practical" reactivity of a coke experimentally, that of any other type of coke can be calculated mathematically, provided that the heaped weight, average lump size and apparent specific gravity are known. By the insertion of suitable values in the formula for Wolf's pressure-wear testing method, the changes in reactivity, such as occur particularly in blast furnace operation, can be determined. In this way the practical suitability of coke can be checked continuously, because no special reactivity tests are required.

Continuous Tar Distillation with a Pipe Still of the Koppers Type. O. Eisler, Z. Zamrzla, and M. Weinkopf. (Glückauf, 1936, vol. 72, Feb. 22, pp. 184–188). After touching on the usual processes of tar distillation, the authors describe the principles of a new process of distilling tar in a pipe still (previously used in America for distilling mineral oil); the principal feature is the very short period of heating, the result of which is an improvement in the oil yield and the pitch quality. Some results obtained are reported; it is shown that the requirements in regard to heat efficiency and purity of distillate are fully met, from both the economic and technical aspects.

Town Gas in the Ferrous and Non-Ferrous Metals Industries. (Metallurgia, 1935, vol. 13, Dec., pp. 63–66; 1936, Jan., pp. 85–87; Feb., pp. 115–116). The application of town gas to the metal industries is considered under the following headings: Billet heating for forging and drop-stamping, (2) sheet heating, (3) annealing, (4) heat treatment for hardening, (5) the continuous furnace, (6) tool heat-treatment furnaces. The author goes on to explain the system of atmosphere control adopted in town-gas-fired furnaces, and the application of these furnaces to ferrous and non-ferrous industries.

The Use of Town Gas for Vitreous Enamelling. W. Dieterichs and P. Lloyd. (Institute of Vitreous Enamellers: Foundry Trade Journal, 1936, vol. 54, Mar. 5, pp. 194–197). The author discusses the fuel requirements of the enamelling process and compares the various types of fuel—coal, coke, oil, gas, and electricity—from the point of view of suitability and economy. The application of town gas to the processes of melting the frit, and drying and firing the enamel is then further considered.

Viscosity of Fuel Oils. J. H. Hruska. (Industrial Heating, 1936, vol. 2, Feb., pp. 105–106). The Steiner viscosity test is described. (*See* p. 14 A.)

PRODUCTION OF IRON

(Continued from pp. 169 A–170 A)

Some Blast-Furnace Problems for '36. W. A. Haven. (Blast Furnace and Steel Plant, 1936, vol. 24, Jan., pp. 43–46). It is suggested that now that American blast-furnace plants are resuming normal pre-depression outputs attention to certain neglected points—notably the temperature of the blast, the behaviour of the refractories in the hot-blast stove, and the control of the stack-top gas velocities in the blast furnace—is necessary.

Relative Desulphurising Powers of Blast-Furnace Slags. W. F. Holbrook and T. L. Joseph. (American Institute of Mining and Metallurgical Engineers, 1936, Technical Publication No. 690; Metals Technology, 1936, vol. 3, Feb.). The relative desulphurising powers of slags of varying composition have been determined. Data and diagrams are presented giving the relative desulphurising powers at 1500° C. of blast-furnace slags containing 10% or less of MgO. Each oxide was found to have its own effect, and it was not possible to relate the desulphurisation to the "total bases" or "total acids." MgO was observed to be slightly deleterious in acid slags—an effect which became more serious as the basicity was increased to that of slags of average composition; on the other hand, it was favourable to the desulphurisation by the more basic slags. It is suggested that the evolution of carbon monoxide plays an important part (physically) in the process of desulphurisation.

Prevention of Explosions during Slag Granulation. A. Killing. (Stahl und Eisen, 1936, vol. 56, Mar. 26, pp. 387–388). The slag running from blast furnaces and other smelting furnaces contains not inconsiderable quantities of iron, and when this slag is granulated there is a danger of explosions, owing to the reaction of the iron with the water, producing an explosive mixture of hydrogen and air. It is therefore essential that the iron be removed before the slag is granulated. Various methods for doing this have been proposed, including a centrifugal method described by Brosius. The Dortmund-Hoerder Hüttenverein have adopted a simpler expedient. A "settling sump" of refractory material, is included in the channel through which the slag runs; the slag flow slows down in it and the iron settles out. When the sump is full of iron, the slag flow is stopped and the iron is run off into moulds.

Iron Past and Present; its Manufacture and Uses. R. Lowe. (Journal of the Junior Institution of Engineers, 1936, vol. 46, Mar., pp. 263–277). The author presents a review of the early methods of producing and working iron. The development of steel manufacture is touched upon and a number of improvements effected in the production of cast iron are dealt with.

FOUNDRY PRACTICE

(Continued from pp. 171 A–173 A)

Manufacture and Application of Modern Cast Irons. J. W. Gardom. (Manchester Association of Engineers: Foundry Trade Journal, 1936, vol. 54, Mar. 5, pp. 191–193). Some of the recent improvements in foundry practice—such as mechanisation, sand control, and the development of high-test cast irons—are briefly reviewed.

Some Criticisms of the Provisional Report of the Costing Sub-Committee. B. Doran. (Foundry Trade Journal, 1936, vol. 54, Feb. 20, p. 161). The author puts forward some criticisms concerning the recommendations of the Costing Sub-Committee.

Presents Detailed Data for Construction of Small Size Cupola. H. W. Kelly. (Foundry, 1936, vol. 64, Feb., pp. 34, 84). Details of the construction of a small experimental cupola are furnished. The cupola has an internal diameter of 15 in. and is parted at the level of the charging door, for ease of repair; the stack is suspended and the body is provided with wheels and mounted on a short track. The furnace is suitable for melting ferrous and non-ferrous metals.

Contribution on the Blast Supply to the Cupola. H. Schmidt. (Giesserei, 1936, vol. 23, Feb. 28, pp. 107–111). Investigation on a cupola showed that the results of the usual methods of determining the blast volume required did not agree with the actual conditions. By means of examples it is demonstrated that not only must a general excess of air be allowed for, which, owing to the subsequent combustion of carbon monoxide in the upper part of the shaft, is not included in the gas analysis, but also the metal loss by burning must be taken into account when determining the blast volume required.

Malleable Foundry Duplexes with Cupola and Air Furnace. (Foundry, 1936, vol. 64, Jan., pp. 22–24, 63, 64). The melting practice of the foundry of the Eberhard Manufacturing Co., Cleveland, U.S.A., is described. A duplex system is in operation, the metal being melted in a cupola and transferred to an air furnace fired with powdered coal, whence it is poured into the ladles.

Superheats and Refines Grey Cast Iron. E. Bremer. (Foundry, 1936, vol. 64, Jan., pp. 26–27, 67). At the foundry of the Miller Foundry Co., Columbus, Ohio, a new type of furnace has been developed as an adjunct to the cupola. This furnace is actually a rather shallow oil-fired forehearth adjacent to the cupola. It serves both to refine the metal (by means of the sodium carbonate desulphurising process) and to superheat it, and also enables the

carbon content of the iron to be reduced and alloy additions to be made. It has been used for the production of glass moulds and has proved very satisfactory in operation.

Dominion Engineering's Air Furnace for Casting Rolls. (Iron and Steel of Canada, 1935, vol. 18, Dec., pp. 83–84). The air furnace recently put down by the Dominion Engineering Works at their foundry at Lachine, Quebec, is described Of 15 tons maximum capacity, and fired by pulverised coal, the furnace is designed for melting the metal for chilled rolls and high-grade alloy iron and grey-iron castings.

Recent Developments in Cast Iron. J. G. Pearce. (Staffordshire Iron and Steel Institute: Foundry Trade Journal, 1936, vol. 54, Mar. 5, p. 190). The use of inoculants, superheating, and titanium additions in the production of finely graphitic cast iron, the problem of non-metallic inclusions, and the usefulness of alloy cast irons are among the aspects dealt with.

Steel Castings—Properties and Design. F. A. Melmoth. (American Society for Metals: Iron Age, 1936, vol. 137, Feb. 6, pp. 30–33, 94, 95). The author suggests that if proper care is taken to control the process of solidification in steel castings, the latter should be able to compete favourably with steel forgings. It also, he explains, demands the use of good sound steel, adequate melting equipment, efficient design, and the correct moulding technique.

The Manufacture and Utilisation of Electric Steel in the Foundry. T. R. Walker and C. J. Dadswell. (Institute of British Foundrymen: Foundry Trade Journal, 1936, vol. 54, Feb. 20, pp. 157–160). The authors describe the production of basic electric steel for foundry purposes, and then discuss the application of chills, the elimination of pin-holes and cracks in castings of electric steel, and the use of acid electric steel.

Steel Castings are Produced in Moulds Bonded with Cement. P. Dwyer. (Foundry, 1935, vol. 63, Dec., pp. 22–24, 60; 1936, vol. 64, Jan., pp. 30–32, 68, 70; Feb., pp. 28–30, 72–77). The Randupson system of producing moulds, as operated at the Birdsboro Steel Foundry and Machine Co., Birdsboro, Pa., is described. In this process the moulding sand is bonded with Portland cement and water, and the moulds are allowed to set, no drying ovens being used. After casting, the moulds are transferred to the shake-out. The coarse lumps are used as filler, the remainder being pulverised and mixed with fresh cement and water to form the backing sand; the facing sand consists of fresh sand and cement. Large moulds are built up of smaller pre-cast blocks. The author describes, in detail, the procedure followed when producing typical castings, including a steel impeller, a cast rack, and a propeller.

Ford Casts Parts of Alloy Iron and Steel. (Foundry, 1936, vol. 64, Feb., pp. 26–27, 70). The foundry plant and practice adopted by the Ford Motor Co., Detroit, for the production of cylinder blocks, camshafts and valve inserts are described.

Formed Tubes Cast in Grey Iron. (Foundry, 1936, vol. 64, Jan., pp. 35, 75). At the Cleveland Works of the Westinghouse Electric and Manufacturing Co., U.S.A., one of the operations carried out in the foundry consists of casting a protective coating of grey iron around tubular immersion-heater elements; the technique of the operation is briefly outlined.

The Whifflet Foundry of R. B. Tennent, Limited. (Foundry Trade Journal, 1936, vol. 54, Feb. 20, pp. 153–154). **Roll Foundry of R. B. Tennent, Limited.** (Iron and Coal Trades Review, 1936, vol. 132, Feb. 14, pp. 303–304). A short account of the production of " Adamite " rolls at the Whifflet Foundry, Coatbridge, Scotland, is presented. (*See* p. 53 A.)

New Continuous Casting Plant at Derby. (Foundry Trade Journal, 1936, vol. 54, Mar. 5, pp. 187–189). The new foundry of the International Combustion Company, Ltd., Derby, is described. Two balanced-blast cupolas have been put down. The metal from these furnaces runs into a common receiver, and so into ladles serving the continuous casting plant. After use the boxless moulds are automatically discharged from the mould conveyor and carried to the knock-out; here the castings are removed and the sand is conveyed to a Hummer screen, whence it travels to a sandmill; it is then returned to the moulding machines.

Kawaguchi—The Falkirk of Japan. R. Maeda. (Foundry Trade Journal, 1936, vol. 54, Jan. 9, pp. 52–54). Kawaguchi is one of the chief iron-founding centres of Japan. The town itself is situated to the north-west of Tokio, and adjacent thereto. The art of iron founding in the district dates from the 14th century; since that period the industry has steadily grown, receiving considerable impetus during recent times.

Bibliography of Literature on Shrinkage and Contraction in Cast Iron. (Bulletin of the British Cast Iron Research Association, 1935, vol. 4, Oct., pp. 199–213).

Production of Steel Castings. G. T. Hampton. (Staffordshire Iron and Steel Institute, Feb. 7, 1936: Foundry Trade Journal, 1936, vol. 54, Feb. 20, pp. 155, 160). Among other matters the author deals with shrinkage and the application of chills.

PRODUCTION OF STEEL

(Continued from pp. 174 A–176 A)

Corrigan, McKinney Steel Company. C. Longenecker. (Blast Furnace and Steel Plant, 1936, vol. 24, Jan., pp. 75–81). An outline of the origin, development and present productive capacity of the Corrigan, McKinney Steel Co. is given.

The Open Hearth in 1935. K. C. McCutcheon. (Blast Furnace and Steel Plant, 1936, vol. 24, Jan., pp. 47–49). Progress in American open-hearth furnace practice during 1935 is reviewed.

Some Problems of Steel Melting. E. C. Smith. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1935, vol. 116, pp. 13–25). The author deals more particularly with the nature of the slags and refractories used in basic open-hearth practice. He discusses the types of refractories used, and the constitution and petrographic structure of slags and of the slag constituents present.

The Distribution of Sulphur Between Metal and Slag in the Basic and Acid Processes of Steel Manufacture. E. Maurer and W. Bischof. (Iron and Steel Institute, May, 1936; this Journal, p. 183 P.).

Rimming Steels. A. Jackson. (Newport and District Metallurgical Society, Jan. 11, 1936: Iron and Steel Industry, 1936, vol. 9, Feb., pp. 179–182). After referring to the advantages and disadvantages of rimming steels, the author describes some experiments undertaken in the endeavour to produce ingots with a killed core and an outer purer rim. The results obtained by varying the teeming speed and practice, mould conditions, and killing time, are illustrated and discussed.

Production of Stainless, Acid-Proof, and Heat-Resistant Steels in U.S.A. F. F. Chimushin. (Catshestvennaia Stal, 1936, No. 2, pp. 7–16). [In Russian.]

Means of Increasing Production of High-Grade Steel Plants. P. K. Alexeiev. (Catshestvennaia Stal, 1936, No. 1, pp. 21–22). [In Russian.]

Increase of Production of Electrical Furnaces in Winter Conditions. G. F. Dunaiev and S. A. Sacharuk. (Catshestvennaia Stal, 1936, No. 2, pp. 48–50). [In Russian.]

Methods of Increasing Output of Electric Melting Furnaces. K. P. Grigorovitsh. (Catshestvennaia Stal, 1936, No. 1, pp. 7–12). [In Russian.]

Economical Operation of Induction Furnaces. F. Pölzguter. (Steel, 1936, vol. 98, Jan. 27, pp. 30–35). This is an English translation of an article which appeared in Stahl und Eisen, 1935, vol. 55, July 18, pp. 773–779. (*See* Journ. I. and S.I., 1935, No. II., p. 385.)

Slag Control. W. Ash. (Sheffield Trades Technical Societies: Iron and Steel Industry, 1936, vol. 9, Feb., pp. 175–177). The control of the slag in steel-making, and its effect on the quality of the steel, is discussed. Reference is also made to the Perrin process.

Open-Hearth Slags. T. Blundell. (Sheffield Trades Technical Societies: Iron and Steel Industry, 1936, vol. 9, Feb., pp. 174–175). Acid and basic slags are discussed from the steel-melter's point of view.

Steel-Melting Slags. The Chemical Aspect. W. R. Maddocks. (Sheffield Trades Technical Societies: Iron and Steel Industry, 1936, vol. 9, Mar., pp. 213–214). The part played by the slag in the steel refining process is dealt with. The rôle of the slag in controlling the oxidation of the carbon, silicon, manganese, &c., in the acid and basic processes, and in phosphorus removal in the basic process is stressed. Basic electric slags are also referred to.

ROLLING-MILL PRACTICE

(Continued from pp. 179 A–181 A)

The Loading and Friction of Thrust and Journal Bearings with Perfect Lubrication. H. A. S. Howarth. (Journal of the American Society of Mechanical Engineers, 1935, vol. 57, pp. 169–187).

Investigations on Plain Bearings with a New Method of Lubrication at very High Pressures. G. Welter and W. Brasch. (Metallwirtschaft, 1936, vol. 15, Mar. 6, pp. 227–229). Laboratory tests are recorded to show the superiority of a new method of lubricating plain bearings working under heavy loads; the diameter of the axle used was 120 mm. The feature of the new system lies in the fact that, besides the normal lubrication, additional lubricant is forced under very high pressure (100–200 atm.) into the bearing at the point of maximum load; the result is the formation of an oil film between the axle and the bearing which entirely prevents metallic contact. The test curves reproduced indicate that with the new system the friction is actually less than that with a roller bearing.

The Merchant Iron and Wire Rod Mill at the Pretoria Steelworks. (Iron and Steel Industry, 1936, vol. 9, Feb., pp. 163–166). The new mill installed at Pretoria, South Africa, is designed to be highly flexible, yet economical in operation. It is capable of producing merchant stock (rounds, squares, flats, &c.), light angles and tees, rails and wire rod. The main items of the mill are as follows: A Morgan continuous billet furnace; a three-stand continuous roughing train, and a four-stand continuous roughing train (by-pass for medium and thick sections); the finishing mill, consisting of a three-stand, a two-stand and a one-stand group; and the continuous wire finishing mill, which comprises five stands. The mill is also equipped with coiling, shearing, and auxiliary plant.

A Modern Development in Sheet Rolling. (Iron and Steel Industry, 1936, vol. 9, Feb., pp. 186–187). The operation of the Lewis three-high mill for the production of sheets is described. Served by a reheating furnace 60 to 75 ft. long, and incorporating a double conveyor row (giving an effective length of 120 to 150 ft.), the mill deals with the bars in pairs; on the third pass the bars are matched and subsequently passed through together. In five passes it is possible to reduce a bar 0·5 in. thick to 18 gauge.

Some Considerations Influencing Plant Facilities for Strip-Sheet Production under British Conditions. G. A. V. Russell. (Iron and Steel Institute, May, 1936; this Journal, p. 51 P.).

Co-ordinated Design and Operation Feature McDonald Hot Strip Mill. (Steel, 1936, vol. 98, Feb. 24, pp. 32–37, 57). The new 43-in.

continuous hot strip mill of the Carnegie-Illinois Steel Corp. is described. (*See* p. 62 A.)

Modern Developments in Cold-Rolling Mills. C. E. Davies. (Metallurgia, 1936, vol. 13, Feb., pp. 107–108). Notes on the present tendencies in the design of modern cold-rolling mills are furnished.

Modern Tube Production and Tube Welding Technique. F. Schröder. (Internationale Röhrenindustrie, 1936, vol. 1, Feb., pp. 2–4). A cursory review of the manufacture of tubes.

Hydraulic Manipulator of Welded Rolled Steel. J. D. Knox. (Steel, 1936, vol. 98, Mar. 9, pp. 58–61). A new hydraulic manipulator has been built for the Jones and Laughlin Steel Corp., Pittsburgh, to serve their 44-in. reversing blooming mill. It is furnished with four movable platens, two on each side of the mill; the platens are provided with manipulator heads, operated by hydraulic power. The machine was fabricated from rolled steel plates by the electric arc welding process.

HEAT TREATMENT

(Continued from pp. 182 A–183 A)

Progress in Melting and Heat Treatment Furnaces. (Metallurgia, 1936, vol. 13, Jan., pp. 73–76; Feb., pp. 133–135). The new types of melting and heat-treatment furnaces recently installed in British plants are reviewed. Nitriding, continuous annealing, and crucible furnaces are dealt with.

Metallic Cementation (VIII.). Cementation of Some Metals by means of Titanium (Ferro-Titanium) Powder. T. Kase. (Kinzoku no Kenkyu, 1936, vol. 13, Feb. 20, pp. 50–60). The cementation of iron, nickel, and copper at various temperatures between 800° and 1300° by means of powdered ferro-titanium was investigated. The depth of penetration was measured, microscopic and chemical analysis was carried out, and the corrosion of the cemented layer by acids was studied. It was found that titanium diffuses into iron, copper, and nickel at a temperature higher than about 800°, the rate of diffusion increasing with rise in temperature. In the case of iron the diffusion rate increases abruptly at the A_3 point. The relation between the increase in weight of the specimen (ΔW) or the depth of penetration (P), and the absolute temperature of cementation (T) or the time (θ) required for treatment is given by the function ΔW (or P) $= ae^{-b/T}$, or ΔW (or P) $= a\theta^{b\theta}$, where a and b are different constants in each case. Although the cemented surfaces are harder than the original material, they are scarcely more resistant to corrosion.

Steels for the User.—XVI. Case-Hardening. R. T. Rolfe. (Iron and Steel Industry, 1936, vol. 9, Feb., pp. 193–196). The principles underlying the case-hardening process are explained, with particular reference to the treatment of a gudgeon pin, as being typical of case-hardening practice. Both pack-hardening and paste-carburising are considered.

Case Hardening of Steel with Gases Produced by the Pyrolysis of Crude and Other Oils. N. A. Minkievitsh, S. R. Iljinsky, and V. N. Prosvirin. (Catshestvennaia Stal, 1936, No. 2, pp. 31–43). [In Russian.]

Local Surface Hardening. (Machinery (Lond.), 1936, vol. 47, Feb. 13, pp. 601–604). The Shorter process of surface hardening is described; the application of the process, the results obtainable with it, and the procedures adopted in hardening gear teeth, crankshafts, &c., are briefly outlined.

The Shorter-Double-Duro Process for Surface Hardening. (Engineering, 1936, vol. 141, Mar. 6, pp. 273–274). The extended Shorter surface-hardening process is described.

Silicon-Manganese Spring Steel and Its Heat Treatment. G. N. Fomin and S. A. Berner. (Catshestvennaia Stal, 1936, No. 1, pp. 34–39). [In Russian.]

Methods of Hardening Cast Iron by Heat Treatment. J. S. Vanick. (Metal Progress, 1936, vol. 29, Jan., pp. 40–43). A review of the hardening properties of intrinsically hardenable cast irons (such as those containing silicon, nickel, and chromium as alloying elements) is presented, together with brief notes on nitriding and case-hardening as applied to cast iron.

The New Technical Equipment in the Planned Tool and Heat-Treating Department of the Automobile Plant "Stalin," Moscow. S. L. Rustem. (Catshestvennaia Stal, 1936, No. 2, pp. 43–47). [In Russian.]

Steel for Automobile Frames and its Heat Treatment. G. N. Fomin and S. A. Berner. (Catshestvennaia Stal, 1936, No. 1, pp. 39–43). [In Russian.]

The Temperature History during the Constant-Rate Heating of a Solid Circular Cylinder. A. B. Newman and A. H. Church. (Transactions of the American Society of Mechanical Engineers, 1935, vol. 57, pp. A 96–A 98). The authors present a solution of the partial-differential equation for heat conduction in a solid circular cylinder for the condition where the heat is forced into the cylindrical surface at a constant rate. A mathematical analysis is made of the temperature-history curve at the heated face and at the axis of the cylinder, and the results are reduced to tabular and graphical form for practical application.

The Lindberg Cyclone Tempering Furnace. (Wire and Wire Products, 1936, vol. 11, Feb., pp. 80–81). The Lindberg tempering furnace operates on the principle of convection heating. Air is circulated by means of a fan through a closed system consisting of the container holding the parts to be heated and an adjacent chamber containing electric heating elements. It is claimed to give uniformity and accurate temperature control.

WELDING AND CUTTING

(Continued from pp. 184 A–185 A)

Latest Developments in Welding. R. Granjon and J. Brillié. (Seventh International Congress on Mining, Metallurgy, and Applied Geology, Paris, Oct. 20–26, 1935, Metallurgical Section, vol. 1, pp. 313–319: Revue de Métallurgie, Mémoires, 1936, vol. 33, Feb., pp. 89–95). A review of recent progress in the welding of iron and steel; attention is given to the parent metal, electrodes, and filler rods.

The Phenomenon of the Erratic (Unstable) Welding Arc. G. M. Tichodeev. (Journal of the American Welding Society, 1936, vol. 15, Feb., pp. 13–17). Experiments on the stability of the welding arc are described, in which the behaviour of welding rods lightly coated with different metallic oxides was studied. It is shown that the stability of the arc depends on the presence—in the rod itself, or the coating of the rod—of certain metallic substances. Certain materials—such as FeO, CaO, MnO—help to steady the arc; others—notably aluminium, Al_2O_3, and silica—give an erratic arc. Ferrous sulphate, arising from insufficient washing of the wire after pickling, may also give rise to instability. The effect of the stabilisers or non-stabilisers on the behaviour of the arc may be accounted for by considering the conditions of electron emission.

Aircraft Requires Welding in many Parts. C. de Ganahl. (Metal Progress, 1936, vol. 29, Feb., pp. 61–63). It is explained that chromium-molybdenum steel of the grade used for aircraft construction may readily be welded by the oxy-acetylene process, if a suitable heat treatment is subsequently given. Electric resistance welding has not proved satisfactory, owing to the rapid natural quenching which obtains, leading to embrittlement. Austenitic nickel-chromium steel, on the other hand, besides being stainless, has proved highly amenable to spot welding.

Composition of Electrode Coatings. C. J. Holslag. (Journal of the American Welding Society, 1936, vol. 15, Feb., p. 12). The author briefly indicates the various materials which enter into the composition of electrode coatings.

Cutting Structural Steel. J. H. Zimmerman. (Journal of the American Welding Society, 1936, vol. 15, Feb., pp. 21–25). A comparative study of the effects on the metal of cutting by machining, friction sawing, shearing, and flame cutting (by hand and by machine) is presented. The influence of each method on the microstructure and hardness of the metal adjacent to the cut surface, and the ductility and impact resistance of the surface metal were

investigated. From the results obtained it is concluded that the disturbance of the hardness and structure of the structural-steel plate used in the tests is less severe in flame-cutting than with shearing or friction sawing. Machine flame-cutting scarcely affects the toughness of the metal adjacent to the cut surface, hand flame-cutting definitely improves it, and shearing or friction sawing decrease it slightly. The ductility is less seriously affected by flame-cutting than by shearing or friction sawing.

The Effect of Molten Solder on Some Stressed Materials. G. Wesley Austin. (Journal of the Institute of Metals, 1936, vol. 58). Breakages of steel and non-ferrous parts during assembly by soldering whilst subjected to stress, led to this investigation on the effect of molten solder on stressed tensile test-pieces of many of the metals and alloys used in engineering. Although the phenomenon was found to be very general, certain materials proved less susceptible than others; a selection of materials which will offer resistance to the simultaneous action of stress and solder is thus possible.

Nitrogen in Metallic Arc Weld Metal. J. W. Miller. (Journal of the American Welding Society, 1936, vol. 15, Feb., pp. 5–10). A study was made of the effect of nitrogen on the welding operation and the character of the weld metal. The weld metal was examined by X-rays; an investigation of the effect of the nitrogen content of the welding atmosphere upon the nitrogen content of the deposited weld metal, and of the carbon content and size of the electrode upon the nitrogen in the weld metal was also undertaken; the influence of the electrical conditions (amperage, voltage and polarity) was investigated, and physical tests on the weld metal were carried out. The author, in his conclusions, suggests how the absorption of nitrogen may be diminished, indicates the form in which the nitrogen is present, and describes the conditions which lead to the absorption of nitrogen.

The Metallurgy of " Pure " Iron Welds. G. E. Doan and W. C. Schulte. (American Institute of Mining and Metallurgical Engineers, 1936, Technical Publication No. 694; Metals Technology, 1936, vol. 3, Feb.). Experiments on the production of welds, using welding rods and plates of carbonyl iron, and atmospheres of argon and air (with covered or bare rods), were carried out. The authors discuss the quality, microstructure, and tensile properties of the welds so produced. With iron, the welds made in argon were quite sound, but those made in air exhibited porosity, even when covered electrodes were employed. Steel welds made in argon were observed to be porous. The yield point and ultimate strength of iron welds in argon were lower, and the ductility was very much higher, than when welding was performed in air. Coated electrodes (in air) yielded intermediate values; with steel, however, the presence of the coating gave results superior to both the coated pure iron welds and to the bare steel welds. Age-hardening was observed

in iron welds and steel welds in air, but not in iron welds in argon.

The Creep Strength of Welded Boiler Plate. C. Appaly. (Technische Hochschule Breslau, Dr.-Ing.-Diss., 1935). The author records the results of his creep tests made on welded specimens of boiler plate and, for comparative purposes, on similar but unwelded plate. The creep strength of the welded joint was found to be greater than that of the parent plate and that of the melted-down filler metal. This increased creep strength was due to the occurrence in the welded joint of internal stresses and microstructural forms which hindered deformation. This was demonstrated by subjecting the joint to an annealing treatment; the removal of the internal stresses and the alteration of the structure to resemble that of the parent metal caused the creep strengths of the plate and joint to become practically alike. After heat treatment for 30 min. at 930° C., practically no decrease occurred in the creep strength of the unwelded comparison specimen, but that of the welded specimen dropped considerably, to just under the value for the unwelded comparison test-piece. Annealing for 30 min. at 650° C. brought the creep strength of the welded bar down to just above that of the comparison specimen. The effect of the first heat treatment was due to the removal of internal stresses and the change of structure; that of the second was the result of stress relief only.

COATING OF METALS

(Continued from pp. 187 A–194 A)

Mesle's Chord Method For Measuring the Thickness of Metal Coatings. W. Blum and A. Brenner. (National Bureau of Standards Journal of Research, 1936, vol. 16, Feb., pp. 171–184). In the " chord " method of estimating the thickness of a metal coating the latter is locally removed, by means of a cylindrical grinding wheel of known radius in the case of a plane surface, or by a file if the surface is curved. The thickness of the coating is computed from the width of cut (*i.e.*, the chord) and the radius of the wheel or curved surface. The authors have made a study of this method. Tests on coatings of known thickness showed that the results are accurate to within about 10% for coatings at least 0·0002 in. thick; for thinner coatings the method is not sufficiently precise.

Methods of Detinning Tinplate for Examination of the Thickness and Continuity of the Alloy Layer. A. W. Hothersall and W. N. Bradshaw. (Iron and Steel Institute, May, 1936; this Journal, p. 225 P.)

An Electrolytic Test for Zinc Coatings on Wire. S. C. Britton. (Journal of the Institute of Metals, 1936, vol. 58). A test for zinc coatings on wires has been designed to overcome the objections to tests based on chemical dissolution. Two tests are proposed: A stripping test designed to estimate the weight of coating which must be removed by uniform attack before the iron base is exposed, and a wrapping treatment followed by a stripping test designed to gauge the liability of a coating to crack. The stripping test is carried out by electrolysis in a specially designed cell, a fixed current density being employed so that each unit of testing time corresponds to a known weight of coating; at the end of the test, a short dip in copper sulphate solution serves to show whether the iron base has been exposed. The test is primarily intended to ascertain whether a coating meets a specification, but can be used to determine the actual thickness of coatings. Potential measurements made during stripping provide information as to the structures of coatings. Thus, it has been shown that close-wiped coatings and galvannealed coatings consist almost entirely of zinc-iron alloy. Field tests are demonstrating that the test described gives satisfactory results for conditions of atmospheric exposure, while the Preece test has marked shortcomings.

Theory and Practice of Chromium Plating. N. D. Birükoff and S. P. Makariewa. (Korrosion und Metallschutz, 1935, vol. 11, Dec., pp. 265–278). The conclusion of a series of articles on chromium plating (*see* Journ. I. and S.I., 1935, No. II., p. 451). The

mechanism of the electrolytic deposition of chromium and the composition of the layer of electrolyte at the cathode are discussed, and the influence of chemical and physical factors on the deposition of chromium is dealt with.

Studies in the Theory of Chromium Electrodeposition. R. R. Rogers. (Transactions of the Electrochemical Society, 1935, vol. 68, pp. 391–415). The theories which seem to apply to the deposition of the more noble metals from aqueous solutions do not apply in general to the base metals. Selecting the electrodeposition of chromium as a typical case, numerous experiments were carried out under widely different conditions. The results support the conclusions: (1) That the film of electrolyte in intimate contact with the cathode is more alkaline than the main body of the bath; (2) that this film must have a definite *p*H value for metal deposition to take place; (3) that the final reduction of chromium to the metallic state is due to atomic hydrogen and not to a mere electron exchange between the cathode and positively charged metal ions; and (4) that the amount of atomic hydrogen available at the cathode must be maintained within well-defined limits. The theory developed undoubtedly has general application. Evidence is presented in support of the theory that even the most active metals may be electrodeposited from aqueous solutions.

Bonding of Metals. (Ironmonger, 1936, vol. 203, Feb. 22, pp. 99–100). Brief mention is made of a new metal-bonding process which is said to enable ingots, slabs, &c., to be united, provided that the metals have melting points above about 1200° C. Illustrations of clad specimens are reproduced, but no details of the process are given.

A Study of Al–Hg–Zn Anodes in Acid Zinc Plating Baths. A. K. Graham and P. G. Kolupaev. (Metals and Alloys, 1936, vol. 7, Jan., pp. 14–17). A study of Al–Hg–Zn anodes in a $ZnSO_4$–$Al_2(SO_4)_3$–NH_4Cl bath at *p*H values of 2·0 to 4·0 and three other acid zinc baths of commercial composition at a *p*H value of 4·0 was made. Temperatures up to 50° C. and current densities as high as 300 amp. per sq. ft. were employed. The current efficiencies, anode polarisation and sludging tendency, bath voltages and *p*H variations, and character of the deposits are reported upon. The results are compared with those obtainable with pure zinc anodes.

Corrosion After Pickling Major Source of Galvaniser's Dross. W. G. Imhoff. (Iron Age, 1936, vol. 137, Feb. 20, pp. 30–33, 51). A study of the action of magnetic oxide of iron in forming zinc dross in galvanising baths is reported. Melts of zinc and magnetic oxide were made at temperatures between 800° and 1565° F.; they were examined under the microscope and by chemical means. The author describes the results obtained and draws the following conclusions, amongst others: (1) Molten zinc reduces magnetic oxide of iron to form galvaniser's dross; (2) the reducing action of molten zinc on Fe_3O_4 is less severe than that on Fe_2O_3; (3) the introduction

of iron into the zinc greatly increased its hardness; (4) dross did not appear until a temperature of 950° F. was reached, and the reducing action did not become violent until 1100° F. was attained, at which temperature zinc oxide began to form, the melt becoming pasty; (5) at 1300° F. the zinc oxidised very rapidly; (6) at 1565° F. the melt consisted of a dark green granular material (zinc oxide) and very fine dross crystals. (*See* p. 189 A.)

A Study of the Origin of Porosity in the Tin Coating of Tinplate. A. W. Hothersall and J. C. Prytherch. (Iron and Steel Institute, May, 1936; this Journal, p. 205 P).

Application of Gas-Fired Radiant Tubes to Porcelain Enamelling. E. F. Gehrig. (Iron Age, 1936, vol. 137, Feb. 6, pp. 26–29). The gas-fired muffle furnaces used by the Detroit Michigan Stove Co. for the firing of vitreous enamelled stoves, &c., were converted to radiant tube operation; the performance of the reconstructed furnaces is stated to exceed that of the original muffle furnaces.

Protective Materials in Use for Outdoor Structural Work. (Steel, 1936, vol. 98, Feb. 24, pp. 42–43). A general discussion of the degree of protection against the atmosphere afforded by paint is presented.

Paint in the Petroleum Industry. H. B. Footner. (Petroleum Times, 1936, vol. 35, Mar. 28, pp. 399–408). The author surveys many of the problems arising in the utilisation of paint in the petroleum industry with special reference to the painting of storage tanks. The removal of mill-scale from the plates by the use of sand blast and pickling is dealt with and the factors to be considered in the choice of priming and finishing paints are discussed. There are many priming paints marketed at the present time which contain no red lead, but which contain " bodied " linseed or other oils, and dry with considerable gloss. These primers have not such good anti-corrosive properties as red lead paints, and may also be the cause of cracking of the finishing paints when used in warm climates. The best practice is to apply the priming paints by brushing. The spraying of red lead paints is very bad practice, since the paint has to be diluted very considerably to run out at the correct consistency for spraying. With regard to finishing paints, there is no doubt that aluminium paint has a much longer life than any white or grey paint. The repainting of tanks externally and the inside protection of tanks is considered. The author also deals with the painting of pipe lines, buildings, woodwork, transport vehicles and ships.

PROPERTIES AND TESTS

(Continued from pp. 195 A–201 A)

The Arthuis Universal Testing Machine. (Engineering, 1936, vol. 141, Mar. 6, p. 271). This machine is of the vertical hydraulic type, manually operated, and is available in 3-ton and 10-ton sizes. Suitable attachments enable tensile, compression, impact, hardness and cupping tests to be carried out. When performing tensile or cupping tests the load is applied by compression springs working on the ram; when conducting compression, hardness, and crushing tests it is applied by hydraulic pressure, the springs being removed. A spring-loaded tup is used for the impact tests.

Correlation between Metallography and Mechanical Testing. H. F. Moore. (Iron Age, 1936, vol. 137, Feb. 27, pp. 26–29, 106). Some of the metallurgical problems which call for a correlation between the results of mechanical testing and metallographical examination are discussed. These include the mechanism of creep and fracture, ageing, fatigue, ductility, &c.

International Standardisation of the Impact Test on Notched Bars. E. Dupuy, J. Mellon, and P. Nicolau. (Revue de Métallurgie, Mémoires, 1936, vol. 33, Jan., pp. 55–70; Feb., pp. 133–139). After referring to the various proposals that have been made in various countries for the standardisation of the notched-bar impact test, the authors present and discuss the results of their investigation of the influence of the depth of the notch on the values obtained.

The Influence of Cold-Work and of Ageing after Cold-Work on Certain Properties of a Medium-Hard Steel. S. Gerszonowicz. (Chimie et Industrie, 1936, vol. 35, Jan., pp. 27–40). The use of cold-worked steels tends to become more general, particularly on account of their higher elastic limits and ultimate tensile strengths, but the questions arise whether they do not break more easily and whether their "tendency to fracture" does not increase with the length of time in service. The present author has studied the influence of cold-work on those properties which characterise the two modes of fracture, (*a*) due to brittleness, and (*b*) due to fatigue. Using specimens of a steel containing carbon 0·255%, manganese 0·6%, silicon 0·33%, sulphur 0·018%, phosphorus and chromium 0·010% each, and traces of nickel, he examined the influence of cold-work applied by tension, compression and torsion on the notched-bar impact strength and the resistance to repeated impact, after which he investigated the effect of artificial ageing on the impact strength of specimens cold-worked in tension. It is shown that the use of cold-worked steels is very dangerous in circumstances

where the stresses applied may lead to brittle fracture, but that it is of advantage in those cases where the metal is submitted to stresses likely to bring about fracture by fatigue.

The Results of Cold-Working and their Disappearance with Rise of Temperature. G. Tammann. (Zeitschrift für Metallkunde, 1936, vol. 28, Jan., pp. 6–17). A general discussion of the effects of cold-work on the properties of metals (mostly non-ferrous) and the theory of the recovery of the properties as a result of the raising of the temperature.

A Study of the Influence of Varying Degrees of Cold-Rolling and Annealing Temperatures on the Properties of Mild Steel Sheets. Part I. The Influence of Cold-Rolling and Subsequent Annealing Temperatures on the Erichsen Values and Crystal Structure of Thin Mild Steel Sheets. C. A. Edwards, D. L. Phillips, and W. H. E. Gullick. **Part II. The Effects of Varying Degrees of Cold-Rolling and Annealing Temperatures on the Properties of Motor-Car Body Sheets.** C. A. Edwards, D. L. Phillips and C. R. Pipe. (Iron and Steel Institute, May, 1936; this Journal, p. 95 P).

On the Distribution of Internal Stress in Many Twisted Metallic Rods and their Changes due to Annealing. T. Ueda. (Kinzoku no Kenkyu, 1936, vol. 13, Jan. 20, pp. 1–17). The elastic after-effect in metals—including Armco iron and various carbon steels—subjected to twisting, was studied. Of the steels, that having the eutectoid composition exhibited the highest elastic after-effect. The distribution of the internal shear stress in the cross-section of specimens which had attained equilibrium was also measured. On annealing it was found that the stress in the interior of the bar largely disappeared within the temperature range of 300–500° C. for steel and Armco iron. The changes in the physical properties, deformation and microstructure on heating were investigated, and the latent energy due to the presence of internal stress was measured.

An Application of the Interferometer Strain Gauge in Photo-elasticity. R. W. Vose. (Transactions of the American Society of Mechanical Engineers, 1935, vol. 57, pp. A 99–A 102). An illustrated description is given of the interferometer strain gauge used in photo-elastic analysis at the Massachusetts Institute of Technology.

Factors of Stress Concentration Photoelastically Determined. M. M. Frocht. (Transactions of the American Society of Mechanical Engineers, 1935, vol. 57, pp. A 67–A 68).

Marine Machinery Defects—Their Causes and Prevention. S. F. Dorey. (Institute of Marine Engineers, Dec. 10, 1935). The defects most frequently encountered in forgings for the screw-shafts, crankshafts, piston and connecting rods, crossheads, bolts, and other important parts of marine reciprocating engines are dealt with. The conditions giving rise to screwshaft failure are examined; reference is made to corrosion fatigue, and cases of broken shafts are cited. The factors bearing on the fracturing of crankshafts—

such as the method of manufacture, the heat treatment, and presence of stress raisers—are discussed. Examples of failures in piston rods, connecting rods, and crossheads are given, and finally the causes of breakages in bolts are summarised, and means are suggested for their prevention.

Strength of Materials under Combined Alternating Stresses. H. J. Gough. (Iron and Steel Industry, 1936, vol. 9, Jan., pp. 132–137; Feb., pp. 177–178). After giving a summary of a previous paper by the author on the above subject, describing work in which specimens of low-carbon 3·5% nickel-chromium steel, and Silal were subjected to combined cyclic stress (twisting and bending), the author examines the results in terms of the theories advanced to account for fatigue failure under such conditions. He then proceeds to show how in a particular case—that of a crankshaft, for instance—the complex alternating stresses which occur might be investigated.

Further Experiments on the Effect of Surface Conditions on the Fatigue Resistance of Steels. G. A. Hankins, M. L. Becker, and H. R. Mills. (Iron and Steel Institute, May, 1936; this Journal, p. 399 P).

Effect of Surface Rolling on the Fatigue Strength of Steel. O. J. Horger. (Transactions of the American Society of Mechanical Engineers, 1935, vol. 57, pp. A 128–A 136). The author has investigated the effect of cold-rolling on the endurance limit and other related physical properties of steel. The cold-working carried out resulted in an almost negligible reduction in area of the metal. Tests were carried out on 0·3-in. and 1-in. dia. cold-worked specimens without stress concentration. It is shown that the fatigue strength may be increased from 24 to 32%. A mild heat treatment of the specimens after rolling gives 6% additional fatigue strength.

Fatigue of Shafts at Fitted Members, with a Related Photoelastic Analysis. R. E. Peterson and A. M. Wahl. (Transactions of the American Society of Mechanical Engineers, 1935, vol. 57, pp. A 1–A 11). This paper deals primarily with the fatigue of shafts with press-fitted members, a problem frequently arising in connection with rotating machinery involving gears, wheels, couplings, rotors, &c. Failures at the edge of fitted members are not uncommon in practice. A survey is made of existing data, after which a report of fatigue tests on the press-fit problem carried out at the Westinghouse Research Laboratories is given. A related photo-elastic investigation and stress analysis is also reported. Practical expedients for increasing the strength of shafts with fitted members are given. Suggestions for future research along the foregoing lines are made throughout the paper.

Internal Stresses and their Effect on the Fatigue Resistance of Spring Steels. M. L. Becker and C. E. Phillips. (Iron and Steel Institute, May, 1936; this Journal, p. 427 P).

The Correlation of Spring-Wire Bending and Torsion Fatigue Tests. E. E. Weibel. (Transactions of the American Society of Mechanical Engineers, 1935, vol. 57, pp. 501–516). (*See* p. 86 A.)

The Ageing of Steels. A. Sauveur. (Seventh International Congress on Mining, Metallurgy, and Applied Geology, Paris, Oct. 20–26, 1935, Metallurgical Section, vol. 1, pp. 359–362 : Revue de Métallurgie, Mémoires, 1936, vol. 33, Feb., pp. 85–88). The author discusses the ageing of steel after quenching, the ageing of iron-carbon solid solutions, and ageing after cold-work.

The Ageing of Steel. J. Galibourg. (Seventh International Congress on Mining, Metallurgy, and Applied Geology, Paris, Oct. 20–26, 1935, Metallurgical Section, vol. 1, pp. 301–312 : Revue de Métallurgie, Mémoires, 1936, vol. 33, Feb., pp. 73–84). A review of the subject.

The Embrittlement of Alloy Steels. F. C. Lea and R. N. Arnold. (Institution of Mechanical Engineers, 1935). Investigations were carried out on the conditions under which age-embrittlement occurs. It is shown that steels containing 3% of nickel and 1% of chromium, with or without molybdenum, become embrittled under prolonged heating, whether stressed or unstressed. The embrittlement may take place with very little change in the other properties. The apparatus used in the long-time tests is described, and details of a new type of apparatus for subjecting specimens to steady and slowly repeated stresses at high temperatures are given. Although steady stresses of certain magnitudes, allied with high temperature conditions, do not affect the rate of embrittlement, it can be very considerably accelerated by exposing specimens to temperature and to a range of slowly repeated stress superimposed upon a steady stress. Reference is made to the effect on the impact values of cold-drawing age-embrittled steels and to some experiments on heating *in vacuo* and on the rate of cooling after prolonged heating. In an appendix a theoretical investigation of the stresses in a necked tensile test specimen is attempted, and this is applied to certain tests described in the paper to explain the types of fractures obtained from embrittled steels.

Embrittlement of Alloyed Steels on Account of Prolonged Heating. A. M. Borsdyka and S. I. Volfson. (Catshestvennaia Stal, 1936, No. 2, pp. 17–24). [In Russian.]

The Embrittlement of High-Tensile Alloy Steels at Elevated Temperatures. W. E. Goodrich. (Iron and Steel Institute, May, 1936; this Journal, p. 349 P).

Causes and Effects of Brittleness in Steel. C. L. Shapiro. (Heat Treating and Forging, 1935, vol. 21, Oct., pp. 467–472; Nov., pp. 517–520; Dec., pp. 569–574, 576; 1936, vol. 22, Jan., pp. 13–15, 24). The author first enumerates the known types of brittleness in steel and then proceeds to examine and correlate the results obtained by various workers on the subject. He describes the phenomena associated with blue-brittleness and discusses some

torsion tests which he has carried out on specimens of Swedish iron in the blue-heat range. He observes that the stress/strain diagram, and particularly the stepping effect which occurs, may be related to ageing, which in turn is the result of precipitation; on this basis he postulates certain criteria of blue-brittleness. Secondary brittleness is then discussed, particularly the effect of composition, grain size, and rate of testing. Transformation brittleness and red shortness are subsequently treated, and the types of brittleness observed at 120° C. and at temperatures within the γ-range are commented on; finally, an account of temper-brittleness is given.

Metallic Wear. H. W. Brownsdon. (Journal of the Institute of Metals, 1936, vol. 58). The extent to which metallic wear takes place between two metallic surfaces in frictional contact and in the presence of a lubricant is dependent on a number of factors, the relative importance of some of which are briefly reviewed in the light of experimental results obtained on a simple machine described in the paper.

Wear Tests on Alloyed and Unalloyed Cast Steel. K. Roesch. (Giesserei, 1936, vol. 23, Feb. 28, pp. 97–101). The author describes two wear testing machines, each intended to simulate conditions under which metal may have to undergo abrasion. In the first machine the specimen is abraded by a bar moving backwards and forwards under a heavy load, the specimen and bar being immersed in a container filled with dry, fine quartz sand; the conditions resemble those in a grinding mill. The second machine consists of a centrifugal pump which pumps water with fine quartz sand suspended in it; the specimens are fitted into the pump rotor and as segments within the body, and the conditions—low surface pressure and very high velocity—represent those in pumps, turbines, &c. The results of tests carried out with these tests on a variety of plain and alloy steel castings are recorded and discussed. A short bibliography of recent papers on wear testing is appended.

Rail Steel and Rail Wear. L. Sanderson. (Metallurgia, 1936, vol. 13, Feb., pp. 113–114). Brief notes on the quality of rails produced by the open-hearth and Bessemer processes, and on the topic of rail wear, are presented.

Pitting Due to Rolling Contact. S. Way. (Transactions of the American Society of Mechanical Engineers, 1935, vol. 57, pp. A 49–A 58). Pitting is a form of failure which occurs on gear teeth near the pitch circle, on rollers, in anti-friction bearings, and on other machine parts where cylindrical surfaces come in rolling contact under heavy loads. The author has studied the development of this type of pitting and means for its prevention. Tests were carried out on rollers of different materials, with different lubricants, and with various loads. The results of the tests indicate that: (1) A lubricant must be present if pitting is to take place; (2) if the lubricant has a viscosity above a certain critical value, which depends on the load, pitting can be prevented; (3) the nature of

the surface finish on the rollers greatly influences the tendency to pit; (4) nitrided rollers will not pit under conditions that would result in severe pitting of quenched and tempered mild steel rollers, also, pits are smaller on harder surfaces, in general. The author has also calculated the load-carrying capacity for the oil film between two rollers having a common peripheral velocity, and it is shown that the critical viscosity necessary to prevent pitting is far below that necessary to prevent metal-to-metal contact. A small crack in the surface, if filled with oil, will tend to grow, provided it has a certain initial direction. It is suggested that oil penetration of these cracks is the reason for their growth until a particle is separated from the main body of the material, leaving a pit.

Iron-Manganese-Aluminium Alloys with High Permeability and Low Coercive Force. B. G. Livshitz and O. N. Althausen. (Catshestvennaia Stal, 1936, No. 2, pp. 25–31). [In Russian.]

Chromium-Cobalt Magnet Steel with a Low Content of Cobalt. V. A. Erachtin. (Catshestvennaia Stal, 1936, No. 1, pp. 49–55). [In Russian.]

Substitution of Tungsten Magnet Steel with a Chromium Steel with Addition of Molybdenum or Manganese. B. G. Livshitz and N. I. Drosdov. (Catshestvennaia Stal, 1936, No. 1, pp. 56–61). [In Russian.]

Electrical Resistivity of Faraday Steels; Gas Analysis and New Phenomena on Remelting in Radiation Furnace. C. Benedicks. (Iron and Steel Institute, May, 1936; this Journal, p. 455 P).

Heat of Formation of Iron Nitrides. S. Satoh. (Scientific Papers of the Institute of Physical and Chemical Research (Tokyo), 1936, vol. 28, pp. 271–276). By using the observed data on the specific heat of Fe_4N and Fe_2N the heats of formation of these compounds were computed, by means of Nernst's heat theorem, from the equilibrium constants of the systems $Fe–NH_3–Fe_4N–H_2$ and $Fe_4N–NH_3–Fe_2N–H_2$ at high temperatures and compared with those obtained by calorimetric methods. The results were found to be in good agreement.

The Elastic Properties of Steel at High Temperatures. G. Versé. (Transactions of the American Society of Mechanical Engineers, 1935, vol. 57, pp. 1–4). The author deals with the determination of the modulus of elasticity and the modulus of rigidity of steel at temperatures up to 500° C. Both a static and a dynamic method were used and their results are compared. Whereas previously most of the static determinations of these moduli have been made under increasing load, in the tests described they were determined under decreasing load, according to the method proposed by F. L. Everett. The tests show that within certain limits, the results obtained by this method are practically independent of the rate of loading. This appears to be due to a strain-hardening effect occurring under loading and detected upon unloading. The variation of Poisson's ratio with temperature is also discussed.

The Behaviour of Five Cast Irons in Relation to Creep and Growth at Elevated Temperatures. H. J. Tapsell, M. L. Becker and C. G. Conway. (Iron and Steel Institute, May, 1936; this Journal, p. 303 P).

Gases in Metals. C. A. Edwards. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1935, vol. 117; abstract, vol. 116, pp. 239–241). An outline is given of the four main conditions in which gases may be associated with metals, namely, as adsorbed gases, dissolved gases, gases in chemical combination, and gases entrapped in blow-holes or cavities. The occurrence of gases in steels is more particularly referred to.

Hydrogen Permeability and Hydrogen Decarburisation of Steels, Armco Iron, Copper, Nickel and Aluminium at High Pressures. W. Baukloh and H. Guthmann. (Zeitschrift für Metallkunde, 1936, vol. 28, Feb., pp. 34–40). The authors report the results of an investigation of the hydrogen permeability and decarburisation by hydrogen of a large number of tubes of carbon and chromium steels at pressures ranging up to 160 atm. and temperatures between 300° and 900° C. It was found that the amount of hydrogen diffusing through the metal increased with increasing grain size, but decreased with increasing carbon content. The influence of the α–γ transformation on the permeability and decarburisation was determined for all the carbon steels examined. With increasing hydrogen pressure, the permeability increased, becoming constant at and above a pressure of about 120 atm. The relation between the permeability and the decarburisation was found experimentally. A few comparative permeability tests were made on copper, nickel and aluminium; copper and aluminium were found to be practically impermeable to hydrogen.

Carbon in Iron. A. Achenbach. (Giesserei, 1936, vol. 23, Feb. 28, pp. 101–107). The burden of the author's thesis is the great importance of carbon in the metallurgy of iron and steel. After dealing with the genesis of iron ores and the part played by carbon in their formation, he discusses the behaviour and characteristics of carbon as an alloying element in steel, pig iron, and cast iron.

Influence of Grain Size and Alloying Elements on Steel Quality. E. C. Bain. (Catshestvennaia Stal, 1936, No. 1, pp. 23–34). [In Russian.]

A Summary of Information on the Preparation and Properties of Pure Iron. J. G. Thompson and H. E. Cleaves. (National Bureau of Standards Journal of Research, 1936, vol. 16, Feb., pp. 105–130). On the basis of the knowledge extant concerning high-purity iron the authors discuss the varieties of so-called "pure" iron which have so far been prepared, and then proceed to summarise the available information concerning the physical properties of high-purity iron.

On the Reduction of Small Quantity of Oxygen Contained in

Reduced Iron by Hydrogen Gas. M. Fukusima and K. Endô. (Kinzoku no Kenkyu, 1936, vol. 13, Feb. 20, pp. 44–49). In order to obtain pure iron free from oxygen the small quantity of oxygen present in electrolytic iron and reduced iron has been removed with hydrogen at high temperatures. The degree of reduction was measured by the continuous observation of the decrease in the volume of hydrogen in contact with the sample. It was observed that the reduction of these small quantities of oxygen was very difficult, and not complete even at temperatures as high as 1250°.

Grey Cast Iron. J. W. Bolton. (Foundry, 1936, vol. 64, Jan., pp. 36–37, 76, 78; Feb., pp. 35, 86–88). Continuing this series of articles on the properties of cast iron, the author discusses the effects of molybdenum, aluminium, and arsenic on the physical, chemical, and metallographical characteristics of the metal. The effects of antimony, barium, bismuth, cadmium, calcium, cerium, cobalt, and copper are also dealt with. (*See* p. 144 A.)

Application of Alloy Steels. H. W. McQuaid. (Heat Treating and Forging, 1936, vol. 22, Jan., pp. 19–24). A general account of the part played by alloy steels in aircraft, automobile and kindred applications is presented.

Properties of the 9% Chromium Steel. H. D. Newell. (Metal Progress, 1936, vol. 29, Feb., pp. 51–55). In an attempt to obtain a steel suitable for use in oil-refinery practice an alloy containing carbon 0·15% (max.), manganese 0·50% (max.), silicon 0·50% (max.), and chromium 8–10% was developed. To improve the mechanical properties different amounts of molybdenum, vanadium, and tungsten were incorporated in the experimental melts. Creep tests and tests for resistance to oxidation were performed, in addition to the usual mechanical tests. Molybdenum, as an additional alloying element, was found to be most effective in raising the creep resistance; the alloy finally chosen contains 1·25–1·75% of this element, the nominal composition being, chromium 9·25%, molybdenum 1·5%, and carbon 0·12%. Described as semi-stainless, the alloy is said to be suitable for applications such as furnace tubes and heat exchangers, where temperatures up to 1250° F. are met with, as in oil refining.

Structure and Properties of Six Per Cent. Chromium Steel and Its Modification with Molybdenum. A. M. Borsdyka and S. I. Volfson. (Catshestvennaia Stal, 1936, No. 1, pp. 43–48). [In Russian.]

Stainless Steels. W. H. Hatfield. (Institution of Production Engineers, 1936, vol. 15, Feb., pp. 47–77). A general account of the development, application, and rust-resisting properties of the chromium and nickel-chromium stainless steels is given. Notes on the manipulation of these steels are appended.

Essays on the History of the Manufacture of Armaments in France up to the Middle of the XVIII. Century. A. Basset.

(Mémorial de l'Artillerie Française, 1935, vol. 14, pp. 881–1280). In chapter I. the author discusses the relations of the military authorities and industry, the origin of the manufacture of armaments, metallurgy in Europe from the fifteenth to the eighteenth century, coal, and mineral legislation. Chapter II. deals with the problems of the manufacture of artillery, progress introduced into the methods, the chemistry of the metals employed (tin, copper, iron), the use of the metals and the pieces to be cast. In chapter III. reference is made to the carefully guarded secrets of the foundryman, chapter IV. deals with the armament politics of Richelieu and Colbert, while the Royal Establishments (arsenals) are described in chapter V., and the powder factories and their processes in chapter VI. Chapters VII. and VIII. deal with portable arms and their manufacture in France, respectively.

The Production of Nickel-Free Metals for Artillery and Armour. H. von Jüptner. (Montanistische Rundschau, 1936, vol. 28, Mar. 1, pp. 1–7). During the World War, Germany and her allies were seriously embarrassed by a shortage of nickel for use in the manufacture of armaments. The author gives the results of mechanical tests made on a number of nickel-free steels during his search for steels that could be used for gun barrels and heavy armour, the results being compared with those given by nickel steels normally used for these purposes.

Trends in the Metallurgy of Low-Alloy High Yield Strength Structural Steels. H. W. Gillett. (Iron Age, 1936, vol. 137, Feb. 27, pp. 40–43, 51). After pointing out the need for new types of structural steel combining low first cost (and hence low alloying additions) with a high yield point and adequate toughness and ductility, the author proceeds to enumerate the physical and chemical properties of those steels which have been developed to meet this need. He indicates the extent to which inexpensive alloy additions—such as those of copper, phosphorus, and manganese —have been incorporated, and the properties they confer.

Skyscraper Born 50 Years Ago ; Raised on Steel. V. G. Iden. (Steel, 1936, vol. 98, Feb. 24, pp. 16–18). The history of the skyscraper and of the parallel development of the adoption of steel sections in building construction is briefly sketched.

British Standard Specification for Structural Steel for Bridges, and General Building Construction. (British Standards Institution, No. 15–1936).

METALLOGRAPHY AND CONSTITUTION

(Continued from pp. 147 A–149 A)

Industrial X-Rays. R. C. Woods. (Metals and Alloys, 1936, vol. 7, Feb., pp. 45–50). The nature, production, and application of X-rays are explained in an elementary way.

Some Applications of X-Rays to Industrial Problems. J. R. Townsend and L. E. Abbott. (Metal Progress, 1936, vol. 29, Feb., pp. 64–70, 86). The authors briefly outline the principles of X-ray technique as applied to industrial problems, and then proceed to discuss the sensitivity of the method under operating conditions. They refer more particularly to the ability of the method to detect cracks and discontinuities in cast and welded products, and distinguish the component parts of composite articles.

Stereometric Measurements on X-Ray Photographs. A. Matting. (Giesserei, 1936, vol. 23, Jan. 3, pp. 7–11). The author discusses the principles of stereometry and their application to the making of X-ray photographs, and then describes the mode of taking the photographs, viewing them stereometrically and making measurements on them.

Investigations on X-Ray Intensifying Screens. R. Berthold and M. Zacharow. (Zeitschrift für Metallkunde, 1936, vol. 28, Feb., pp. 40–42). The authors first discuss briefly the two factors —contrast and sharpness—which determine the quality of a radiograph, their relation to the thickness of the article examined and hence to the voltage employed in the X-ray tube, and the resulting implication with regard to the use of intensifying screens. They then present the results of their experiments, which had the following objects in view : The determination of the intensifying factor of various screens in relation to the quality of the radiation; the comparative determination of the sharpness obtained with different screens; and the determination of the ability to observe defects in the object examined in exposures made with and without screens in relation to the thickness of the object.

The X-Ray Investigation of Fine Structure in Foundry Practice. A. Karsten. (Giesserei, 1936, vol. 23, Jan. 31, pp. 57–59). A general discussion of the X-ray investigation of the fine (atomic) structure and its importance in foundry practice is followed by a description of the apparatus and protective devices used in carrying it out.

On Alpha Martensite in Carbon Steels. Z. Nishiyama. (Kinzoku no Kenkyu, 1936, vol. 13, Feb. 20, pp. 37–40). On the basis of the view that tetragonal or alpha martensite is an interstitial solid solution of carbon in iron, the lattice constants of the martensite

were calculated from the radii of the spheres of action of the iron and carbon atoms. The calculated and observed values were found to agree fairly well.

Experimental Study of the Heterogeneity of Metals and Alloys. A. Portevin and P. Chevenard. (Seventh International Congress on Mining, Metallurgy and Applied Geology, Paris, Oct. 20–26, 1935, Metallurgical Section, vol. 1, pp. 321–338: Revue de Métallurgie, Mémoires, 1936, vol. 33, Feb., pp. 96–113). The authors first discuss the origin of heterogeneity and outline the methods used for investigating it. They then present the results of their experiments, carried out on steels and ferro-nickels, in regard to heterogeneity of solidification, retardation of the solution of a constituent, heterogeneity due to precipitation from a hyper-quenched solid solution, and the influence of various factors in tempering, quenching, cold-working after quenching, and of stress during tempering, on it. They next present a micromechanical study of heterogeneity in untreated and treated material and also of the complex heterogeneity in welds.

The Formation of Globular Eutectic Inclusions in Metal Alloys. W. Geller. (Metallwirtschaft, 1936, vol. 15, Feb. 7, pp. 141–142). In alloys of iron and of aluminium which form eutectics, globular inclusions of a eutectic nature are often observed; the conditions governing their formation are discussed by the author. Rapid cooling through the temperature range just above the solidus is essential; in the as-cast condition, therefore, the phenomenon is only observed when the temperature interval between the solidus and liquidus is small.

Transformation Twinning of Alpha Iron. A. B. Greninger. (American Institute of Mining and Metallurgical Engineers, 1936, Technical Publication No. 689; Metals Technology, 1936, vol. 3, Feb.). An X-ray and optical study of the orientation relationship and the habits of transformation twins in pure α-iron was carried out. It was found that, in general, any one α-iron grain contains (1) twin bands, (2) smaller twin grains, or (3) has a twin relationship to one or more of its neighbouring grains. The habits of transformation twins are affected by varying the speed of cooling through A_3, the banding tending to disappear with very slow cooling speeds. A brief study of annealing twins in α-iron is reported; it is concluded that annealing twins are only a minor structural constituent of annealed α-iron. The mechanisms that have been proposed to explain the $\gamma \longrightarrow \alpha$ transformation in iron would produce twinned structures, but do not account for the relationship between transformation twins recorded in the paper.

The Iron-Aluminium-Carbon System. R. Vogel and H. Mäder. (Archiv für das Eisenhüttenwesen, 1936, vol. 9, Jan., pp. 333–340). By means of heating and cooling curve determinations and micro-examination the constitutional diagram of the iron corner of the iron-aluminium-carbon diagram has been worked out. Six primary

saturation planes were determined, at which the following crystal types precipitate as the temperature falls: (1) Ternary α solid solution, (2) ternary γ solid solution, (3) ternary ε solid solution, (4) ternary δ solid solution, (5) graphite, and (6) crystals of the compound Al_4C_3. The conditions during freezing are represented by the following four-phase equilibria:

(1) Melt + α solid solution + γ solid solution $\rightleftharpoons$ ε solid solution.
(2) Melt + γ solid solution $\rightleftharpoons$ ε solid solution + graphite.
(3) Melt + δ solid solution $\rightleftharpoons$ ε solid solution + Al_4C_3.
(4) Melt $\rightleftharpoons$ ε solid solution + graphite + Al_4C_3.

The transformations in the solid state are determined by the following four-phase equilibria:

(1) ε solid solution + Al_4C_3 $\rightleftharpoons$ δ solid solution + graphite.
(2) ε solid solution + γ solid solution $\rightleftharpoons$ α solid solution + graphite.
(3) ε solid solution + graphite $\rightleftharpoons$ α solid solution + δ solid solution.

The temperature of the ledeburite eutectic is lowered by additions of aluminium; the pearlite transformation is shifted to higher temperatures, and extends over a temperature interval which widens with increasing aluminium content. Above a certain minimum, additions of aluminium favour graphite precipitation. No alteration of the amounts of graphite precipitated by increasing additions of aluminium in alloys with the iron and carbon in definite proportions could be observed. The white phase noted by other workers is a ternary solid solution of the ε series in the iron-aluminium system.

Two Intermetallic Compounds of Beryllium with Iron. L. Misch. (Naturwissenschaft, 1935, vol. 23, pp. 287–288). Two intermetallic compounds occur in the binary beryllium-iron system; one is $FeBe_2$, which is ferro-magnetic and has a Curie point at 520°, while the other is $FeBe_5$, also magnetic, with a Curie point at a low temperature. These have been examined by means of X-rays.

Beryllium-Iron Alloys. W. Kroll. (Metals and Alloys, 1936, vol. 7, Jan., pp. 24–27). The alloys of iron and beryllium—and particularly those of iron, beryllium, and nickel, and iron, beryllium, and chromium—are described. The strong affinity of beryllium for oxygen and sulphur is then discussed in the light of its action as a deoxidiser and desulphuriser.

A Survey of the Iron-Carbon Diagram near Zero Carbon (below 1000° C.). J. H. Whiteley. (Iron and Steel Institute, May, 1936; this Journal, p. 377 P).

X-Ray Investigation of Fe–Ni Alloys. F. Marschak and D. Slepanow. (Zeitschrift für Elektrochemie, 1935, vol. 41, pp. 599–602). Iron-nickel alloys were produced by electrodeposition in layers 0·02 mm. thick on copper; Debye-Scherrer diagrams were then obtained for each alloy. The alloys were found to be solid solutions; in the range 30–50% of nickel slight heterogeneity

was evident, and in this range the lattice was noticeably extended. This increased lattice constant (3·58 Å.) at 30% of nickel corresponds to the commencement of resistance to chemical and electrochemical attack in this concentration range.

X-Ray Study of Iron-Nickel Alloys. E. R. Jette and F. Foote. (American Institute of Mining and Metallurgical Engineers, 1936, Technical Publication No. 670; Metals Technology, 1936, vol. 3, Jan.). The results of an X-ray investigation of fifteen iron-nickel alloys, subjected to varying heat treatments, are reported. The γ-phase alloy lattice constants were determined over the range 25–100% of nickel where the phase could be retained by quenching. High positive deviations from the additivity rule were observed. The α-phase range up to about 5 atomic % of nickel was also studied, and marked positive deviations were found. Some experiments were made to determine the two-phase region in these alloys; tentative limits for this region are suggested in a diagram. Experiments designed to verify or disprove the existence of compounds or superstructures (ordered atomic arrangements) are also reported. No indication of either was found.

Constitutional Diagram and Magnetic Properties of Platinum-Iron Alloys. L. Graf and A. Kussmann. (Physikalische Zeitung, 1935, vol. 36, pp. 544–551). The authors have determined the structures of the iron-platinum alloy series by means of X-ray and microscopic examinations; the magnetic properties were also investigated. At the iron end of the series, the addition of platinum at first raised the magnetic saturation, but later this decreased when cubic face-centred γ crystals formed. Peculiarities in the lattice structure of the α phase were not observed. With about 26 atomic % of platinum, the alloys consisted almost entirely of γ crystals at room temperature and were no longer ferromagnetic. Between 30 and 70 atomic % of platinum they were strongly ferromagnetic (saturation values up to 14,000 gauss, Curie point at 450° C.); here the " carrier " of the magnetic properties was the cubic face-centred γ solid solution, which transformed below 1200° C. into a likewise ferromagnetic compound, FePt (without superstructure). The latter had a Curie point about 100° higher than that of the solid solution of similar composition, and its magnetic saturation was also probably different. In this range the Fe–Pt alloys gave a very broad hysteresis loop with coercive forces of up to 1800 gauss and a remanence of 3000–4000 C.G.S. units—these being the highest values for the magnetic energy content so far known. The primary cause of this broadening of the hysteresis loop is probably the marked lattice distortion set up by the mechanism (resembling that of the martensite transformation) of the transition from the solid solution state into the lattice of the compound.

CORROSION OF IRON AND STEEL

(Continued from pp. 202 A–206 A)

The Fight against Corrosion. (Metaux, 1935, vol. 10, Dec., pp. 285–530). A previous issue of this publication (*see* Journ. I. and S.I., 1935, No. I., p. 517) had been devoted to Part I. of this collection of articles on various aspects of metallic corrosion, under the general group title of "Technical Study." The present issue consists entirely of papers constituting Part II., with the sub-title "Practical Applications." Among the papers are the following :

The Working of Corrosion-Resistant Alloys.

J. CHAMBEYRON : Forging and stamping of rustless steels.
C. AURIBAULT : Boilermaking in rustless steel.
M. LECAT : Stamping of rustless steels of the 18/8 type.
L. ROY : The drawing of rustless steel.
J. LEMOINE : Rustless-steel castings.
R. LAUROUA : The removal of surface defects and the polishing of rustless steels.
E. BOSSI : Structures in 18/8 rustless steel.
E. HERZOG : The working of copper steels.
J. DECORPS : Copper steels in structural work.

Examples of the Use of Corrosion-Resistant Alloys.

G. CHAUDRON : The choice of metals for use in the chemical industry.
L. DELVILLE : Corrosion-resistant alloys in the building industries.
P. CHEVENARD : Alloys capable of resisting high temperatures.

Protective Coatings.

CENTRE D'INFORMATION DE NICKEL : Nickel-clad steel.
R. DE BUYER : Nickel and chromium deposits of great thickness.
M. CAUCHETIER : Metallisation.

Paints in the Fight against Corrosion.

A. VILA : Methods of testing paints.
J. ROUX : Protection of metallic structures against corrosion by paints containing tar or powdered aluminium.

Terminology.

P. BRÈS : Terminology of the rustless steels.

Industrial Documentation.

J. LEMOINE: The 18/8 rustless steels and their industrial applications.

The different corrosion problems and their evolution at the Aciéries Electriques d'Ugine.

LA COMPAGNIE DES FORGES DE CHÂTILLON, COMMENTRY ET NEUVES-MAISONS: Tests on rustless steels.

SOCIÉTÉ DES HAUTS-FOURNEAUX DE LA CHIERS: "Viresco" steels.

SOCIÉTÉ ANONYME D'ESCAUT ET MEUSE: The enamelling of steel tubes with Isolémail, efficacious protection against corrosion.

A.V.O.R. [enamelled corrugated steel sheet for roofs and partitions].

A Simple Apparatus for Corrosion Testing. (Nickel-Bericht, 1935, vol. 5, pp. 121–123). For the corrosion testing of materials under working conditions the simultaneous suspension of a number of specimens is recommended. The specimens are in the form of discs, 56 mm. in dia., with a central hole 9 mm. in dia.; they are slipped on to a bolt and are separated by spacing pieces (short tube lengths). The whole arrangement is held together and protected by end-plates and four holding rods. The suitability of the apparatus and the accuracy of the results have been tested out by a large number of tests under working conditions, of which examples are given.

Guide to the Standardisation of the Experimental Conditions in Corrosion Tests. (Zeitschrift für Metallkunde, 1936, vol. 28, Jan., pp. 20–22). A German tentative specification, referred to as "DIN Entwurf 1, E 1713," for the standardisation of the conditions for carrying out corrosion tests is published.

Is Corrosion Testing Ripe for Standardisation? O. Bauer. (Zeitschrift für Metallkunde, 1936, vol. 28, Feb., pp. 25–29). The standardisation of corrosion tests is only admissible if the results obtained are reproducible. The immersion test in stagnant neutral waters appears to give reproducible results, and is therefore suitable for standardisation. Most of the other corrosion tests (dipping tests, weathering tests, &c.) are dependent to a great extent on external conditions which cannot be controlled, so that for the moment the question of their standardisation does not arise.

Organic Inhibitors of Corrosion. C. A. Mann, B. E. Lauer, and C. T. Hultin. (Industrial and Engineering Chemistry, 1936, vol. 28, Feb., pp. 159–163). After referring to the literature on the subject of organic inhibitors, and explaining the theory of the process in the case of reagents such as the aliphatic amines, the authors proceed to describe some experiments on their behaviour as inhibitors. Specimens of low-carbon steel were immersed in sulphuric acid to which an aliphatic amine had been added, and the corrosion rates were ascertained. The results are reproduced in

graphical form. The blanketing action of these inhibitors arises from the adsorption of inhibitor ions on the metal surface, by way of the nitrogen atom. The stereochemical structure of the aliphatic amines determines their effectiveness as corrosion inhibitors. Long straight-chain aliphatic di- and tri-amines are very effective. The longer the hydrocarbon chains, and the greater the number (up to three) attached to the nitrogen atoms the more efficient is the inhibitor and the less of it required.

Inhibitors. K. B. Lewis. (Wire and Wire Products, 1936, vol. 11, Mar., pp. 127–129, 155). The author discusses the use, behaviour and application of inhibitors in a general way, and describes a simple accelerated test for comparing the efficiency of inhibitors.

Corrosion Problems in the Chemical Industry. J. Golder. (Journal of the West of Scotland Iron and Steel Institute, 1935, vol. 43, pp. 43–48). Examples of the corrosion problems met with in the chemical industry and of the rôle played by the various non-corrodible alloys in solving these problems are cited.

The Influence of Light on the Electrode Potential and Corrosion Phenomena of Mild Steel. C. O. Bannister and R. Rigby. (Iron and Steel Institute, May, 1936; this Journal, p. 293 P).

Factors Influencing the Rate of Attack of Mild Steels by Typical Weak Acid Media. T. P. Hoar and D. Havenhand. (Iron and Steel Institute, May, 1936; this Journal, p. 239 P).

The Solution of Electrodeposits of Fe–Ni Alloys. D. Stepanow, F. Marschak, N. Balaschowa, and W. Kabanowa. (Zeitschrift für Elektrochemie, 1935, vol. 41, pp. 597–599). Electrodeposits of iron-nickel alloys of various compositions were prepared, and their resistance to attack by sea-water, sulphuric acid of various strengths and weak lactic acid was investigated. The existence of a limit of chemical resistance in the alloy series, the position of which depended on the reagent in question, was determined. Also, when the coatings were anodically polarised in solutions in which the iron and nickel concentrations were the same as those used in the production of the coatings, potential measurements revealed a galvanic resistance limit at 35–42% of nickel. From these facts it is concluded that the alloys form an uninterrupted series of solid solutions of iron and nickel, although the possible existence of an intermetallic iron-nickel compound is not excluded.

Durability of Plated Steel Exposed to Weather. W. Blum. (Metal Progress, 1936, vol. 29, Feb., pp. 40–41). After briefly summarising the results of tests carried out by the Bureau of Standards, in conjunction with the American Electroplaters' Society and the American Society for Testing Materials, on the resistance of plated steel to atmospheric conditions (*see* Journ. I. and S.I., 1934, No. II., p. 625, *also* following abstract), the author outlines the specifications which have been formulated on the basis of these tests.

Corrosion-Protective Value of Electrodeposited Zinc and Cadmium Coatings on Steel. W. Blum, P. W. C. Strausser, and A.

Brenner. (National Bureau of Standards Journal of Research, 1936, vol. 16, Feb., pp. 185–211). Atmospheric exposure of plated specimens showed that in a rural or purely marine climate both zinc and cadmium coatings furnished better protection against the corrosion of steel than did nickel or chromium coatings of the same thickness. In an industrial atmosphere, however, both the zinc and cadmium were attacked rather rapidly, the life being roughly proportional to the thickness. Under these conditions the cadmium coatings failed in about two-thirds of the time required for failure of the zinc coatings. Zinc-cadmium alloys containing about 10% of cadmium were superior to either zinc or cadmium. The conditions of deposition did not markedly affect the behaviour of the coatings, while hot-dipped coatings yielded about the same protection as plated zinc coatings of the same thickness. In accelerated tests the life of a zinc coating is roughly proportional to its thickness; cadmium coatings, however, last longer than zinc under the salt-spray test—the latter is not, therefore, a true measure of their behaviour in an industrial atmosphere. The protective value of zinc or cadmium coatings depends on the minimum thickness.

ANALYSIS

(Continued from pp. 151 A–155 A)

A New Vacuum Furnace and its Use for the Determination of Oxygen in Steel. G. Thanheiser and E. Brauns. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1935, vol. 17, No. 18, pp. 207–211 : Archiv für das Eisenhüttenwesen, 1936, vol. 9, Mar., pp. 435–439). A new vacuum furnace is described and illustrated. Its suitability for the hot-extraction method of estimating the oxygen in steel is indicated. The small "blank" in relation to the total gas makes it probable that the furnace can also be used for estimating other gases in steel.

The influence of the manganese content of the specimen on the oxygen determination was examined; it was found to be highly dependent on the working conditions, particularly the cooling. The conditions necessary to obtain, for various manganese contents, the same oxygen values as those given by the standard method in the high-frequency furnace were determined, and the agreement obtained was checked by means of known samples.

The Volumetric Determination of Aluminium in the Presence of Iron Salts. W. Daubner. (Angewandte Chemie, 1936, vol. 49, Feb. 15, pp. 137–138). In a solution containing both aluminium and iron salts, in the presence of acetic acid both metals can be precipitated quantitatively by means of tri-ammonium arsenate, $(NH_4)_3AsO_4$. If carried out in a solution containing the equivalent of 0·45% of arsenic pentoxide the substances produced are tri-aluminium arsenate, $AlAsO_4$, and di-ferric arsenate, $Fe_2(HAsO_4)_3$. The arsenic acid combined in these two compounds can now be estimated volumetrically. Given the iron content of the solution, the arsenic acid combined with it can be calculated, and is then subtracted from the total quantity; the difference represents that combined with the aluminium, from which the content of this metal is calculated. The method is particularly useful for the estimation of aluminium in the presence of iron in silicates, as silica is without influence on the results.

The Titrimetric Determination of Phosphoric Acid in Perchloric-Acid Solution as Bismuth Phosphate. J. Harms and G. Jander. (Angewandte Chemie, 1936, vol. 49, Feb. 1, pp. 106–109). A method for estimating phosphoric acid in perchloric acid solution by titration with bismuth oxyperchlorate, the end-point being determined by the change in the conductivity of the solution (conductimetry) is described. It can be used in the presence of most cations and anions; arsenic must be absent, and ferric iron, nitrates, chlorides and silica should be present in not too large proportions. The

results obtained by this method with various materials containing phosphorus, including basic Bessemer slag, are indicated, and notes on differences of procedure for the different cases are given. The method is very rapid.

Uses and Limitations of the Spectrograph for Industrial Control. T. A. Wright. (Metal Progress, 1936, vol. 29, Jan., pp. 53–57). A general discussion of the field of application of the spectrograph in industry is presented.

The Sampling of Small Coal. E. S. Grumell and A. C. Dunningham. (Fuel in Science and Practice, 1936, vol. 15, Feb., pp. 55–59). The authors offer comments and explanatory notes on the provisions of the British Standard Specification relating to the sampling of small fuel up to 3 in. (B.S.S. 403–1930.)

New Method of Sampling Coal by a Suction Drill Sampling Machine. J. C. Vogel. (Journal of the Chemical, Metallurgical and Mining Society of South Africa, 1933, vol. 34 : Fuel in Science and Practice, 1936, vol. 25, Feb., pp. 48–50). The author describes a form of apparatus suitable for sampling coal at the coal face. It consists of an electric coal drill, the rod of which is enclosed by a tube connected to a suction cleaner. When the drill is in use the sample drilled out is sucked into a filter bag where it is collected. The apparatus may also be used for sampling lump coal.

Studies in Graphite Formation. Part I. The Estimation of Graphite. A. E. Balfour and H. L. Riley. (Reprint, Journal of the Chemical Society, Dec., 1935). The authors point out that the estimation of graphite (in materials such as coke) is beset with difficulties, and they describe an improved oxidation method of carrying out the determination. This depends on the rate of oxidation of finely ground, closely graded samples, by a solution of potassium dichromate in syrupy phosphoric acid; the carbon dioxide evolved is absorbed by soda-lime and weighed. Experiments on the technique of the method were performed, together with tests on samples of coal carbonised at different temperatures; the results obtained are reproduced.

Direct Simultaneous Microdetermination of Carbon, Hydrogen, and Oxygen. W. R. Kirner. (Industrial and Engineering Chemistry, Analytical Edition, 1936, vol. 8, Jan. 15, pp. 57–61). A method of microanalysis is described which enables not only the elementary composition, but also the constitution of bituminous coal and its derived products to be partly determined. The method depends on the gasometric determination of carbon, hydrogen and oxygen by microcombustion; results obtained from two samples of bituminous coal, an alkali-treated coal residue, a nitro-humic acid and a coke derived from bituminous coal are presented.

Critical Investigation of the Ash Determination in Coals. C. Holthaus. (Archiv für das Eisenhüttenwesen, 1936, vol. 9, Feb., pp. 369–387). This is a report of the Sub-Committee for the Investigation of Solid Fuels of the Chemical Committee of the

Verein deutscher Eisenhüttenleute. The research was concerned with the testing out of the determination of the ash content of coal, with particular reference to the ashing temperature, the ash composition at various temperatures and the estimation of the true ash. Tests on a series of coals of various origins pointed to an ashing temperature of 750° C. as the most suitable. By analysing the ash resulting from ashing at various temperatures, those mineralogical constituents of coal which undergo chemical change on subjection to increases of temperature (so altering the ash content) were determined; they were primarily carbonates and sulphates and, to a less extent, the iron compounds; the remaining constituents were practically unaffected. The true ash content was calculated by Thiessen's method of working out the mineral content from the ash analysis, by the direct quantitative determination of the mineral constituents by Mayer's method, and also by several approximate formulæ. Though all methods have greater or less defects, the tests demonstrated the fact of practical importance that the true ash content is not much more than the ash obtained in the usual ashing method; the difference increases with the ash content and with the amount of easily decomposed constituents contained in the coal.

A Microcolorimetric Method for the Determination of Benzene. H. H. Schrenk, S. J. Pearce, and W. P. Yant. (U.S. Bureau of Mines Report of Investigations 3287 : Fuel in Science and Practice, 1936, vol. 15, Jan., pp. 4–8). A method of estimating the benzene present in air is described, in which the benzene is nitrated to *m*-dinitrobenzene with a mixture of fuming nitric and sulphuric acids. The acid mixture is neutralised and extracted with butanone. To the extract sodium hydroxide solution is added; a reddish-purple colour develops which may be compared with suitable standards.

BOOK NOTICES

(Continued from p. 156 A)

BAUER, O., O. KRÖHNKE, and G. MASING, "*Die Korrosion Metallischer Werkstoffe.* Band 1. *Die Korrosion des Eisens und seiner Legierungen.*" Herausgegeben von O. Bauer, O. Kröhnke und G. Masing. 8vo, pp. xxiii + 560 with 219 illustrations. Leipzig, 1936: Verlag von S. Hirzel. (Price 37.50 marks.)

The publication of a review of scientific knowledge in a given field by a group of workers in any country is always a valuable contribution to the advancement of science, since they tend to approach the subject from a different angle, to adduce different and often original data, and to emphasise a different set of conceptions and facts from those stressed by their colleagues in other countries. For this reason, the appearance of the first volume of a German text-book on the corrosion of metallic structural materials, edited by Professors Bauer, Kröhnke, and Masing, is to be welcomed as a noteworthy addition to corrosion literature. This volume, which deals with the corrosion of iron and its alloys, is divided into four main sections:

(1) A general exposition of the theory of corrosion by G. Masing, which serves as an introduction to the whole work, the three subsequent volumes of which will be devoted to the corrosion of non-ferrous metals, methods of protection, and a considered survey of practical experience in the most important fields of service, respectively.

(2) A section on the corrosion of iron, by C. Carius and E. H. Schulz. This comprises a lengthy sub-section on the corrosion of iron as a physico-chemical phenomenon, treated more particularly from the electro-chemical standpoint, followed by a sub-section in which the corrosion of iron is considered as a technological problem, and the authors discuss the effects of various factors, such as chemical composition, the manufacturing, finishing, and fabricating processes, surface condition, and of different corroding media, on the corrosion of commercial steel. The sub-section concludes with a consideration of corrosion-fatigue.

(3) A short discussion by K. Daeves on irons or steels having an increased corrosion resistance, as compared with ordinary steel, without being truly "rust resistant."

(4) A section on acid- and heat-resisting iron alloys, by E. Houdremont and H. Schottky, in which alloys containing chromium, iron-nickel alloys, and iron-silicon alloys are considered.

The general arrangement of the subject-matter is good, and the authors' expositions of their views over the field indicated are very clear. Although authorities who have specialised in fundamental corrosion research might wish to recast a statement here or there, or to throw the emphasis on a different set of factors in certain cases, it is improbable that the ordinary reader will be appreciably misled by accepting the theories presented by the German authors as a reasonable working basis. For example, the mechanism by which small amounts of copper in steel affect its corrosion resistance in various

media is explained with admirable clarity by Carius and Schulz, who were themselves the first to demonstrate that the accumulation of copper at the metal/rust interface is responsible for the increased corrosion resistance of this type of steel in those media in which the copper is deposited in an adherent form.

In view of the scholarly treatment of the whole work, it is doubly regrettable that the book is by no means fully up-to-date in several important respects. With the exception of the last section on corrosion-resistant steels, there are only one or two isolated references in the text to papers published later than 1931, and, as a result, there are some surprising omissions of references to important recent work. For example, there is no reference to Vernon's Bibliography of Corrosion (published in 1928), or to his fundamental work on the effect of solid particles and of humidity on the corrosion of iron, to Bengough's important investigations on the mechanism of corrosion in aqueous solutions, or to the work of Evans and Mears on the probability of corrosion, whilst the subject of corrosion-fatigue is left at the stage when McAdam was just beginning to wonder whether there really was a corrosion-fatigue limit, before the work of Gough and his collaborators had shown that this was not the case. There are some curious omissions regarding German work too; presumably, the work of Bardenheuer and Ploum on hydrogen embrittlement during acid pickling was ruled out as a result of the rather narrow German definition of corrosion as "eine Zerstörung des metallischen Körpers, die durch *unbeabsichtigte* Einwirkung von chemischen Angriffsmitteln . . . stattfindet," but this would surely not exclude the valuable work of Bardenheuer and Thanheiser on the rate of dissolution of copper-bearing mild steels in acids, which is of fundamental importance to corrosion theory, or that of Schröder on the high-temperature oxidation of steel—a subject, by the way, which is not adequately treated in the present volume.

In spite of these omissions, the book contains much interesting original information on corrosion and it is to be regarded as a valuable supplement to the standard works of Evans and of Speller. It is to be hoped, however, that the German authors will make their work a truly worthy member of this trinity by taking care that all future volumes are thoroughly up-to-date at the time of publication, and by revising the present volume in the light of recent developments as soon as possible.

J. C. HUDSON.

HUME-ROTHERY, W. "*The Structure of Metals and Alloys.*" (Institute of Metals Monograph and Report Series No. 1). 8vo, pp. 120, with 60 figs. London, 1936. The Institute of Metals. (Price 3s. 6d.)

This is the first of a series of monographs and reports which the Institute of Metals has arranged to publish in order to provide summaries and reviews of important branches of metallurgical knowledge. It deals with what is usually called the crystal structure of metals and alloys, and not with those other features commonly regarded as the structure, *i.e.* micro- and macro-structure. In the last fifteen years great progress has been made in the study of crystal structure, and this has coincided with pronounced improvements in the experimental methods for determining equilibrium diagrams and with revolutionary changes in the physical theory of electrons and atomic structure. Hume-Rothery has made substantial contributions to the development of knowledge bearing on the relations between atomic structure, crystal structure, and equilibrium diagrams, and this monograph is

a systematic account of these relations as they are understood at present. The first part deals briefly with the structure of the atom, the molecule, and the crystal. The types of atomic combination that give rise to ionic and homopolar molecules are described, and it is then shown that the forces which bind the atoms together in crystals are in many cases the same as those concerned in the formation of molecules. Attention is then given to the linkage of atoms in metal crystals which are neither ionic nor homopolar. In parts 2 and 3 respectively the crystal structure and atomic radii of the elements are considered, and the next two parts are devoted to a description of the structure of the crystals that are formed in alloys. The factors that control the solid solubility of one metal in another are described, and the relations between these and the forms of the liquidus, solidus, and solid solubility curves are considered. In connection with the intermediate phases three types of crystals are distinguished, namely, normal valency compounds, electron compounds, and interstitial structures. In those of the first type the relative numbers of the two sorts of atoms are in accordance with their valency. In those of the second type the relative numbers depend on the ratio of valency electrons to atoms. Thus many pairs of metals form compounds with a body-centred cubic lattice when the two sorts of atoms are present in such proportions that the ratio of electrons to atoms is 3/2. Great importance attaches to these two parts (4 and 5), since they show that the theory of alloy structures is nearing the stage when it will be possible to predict from first principles what may be expected when one element is added to a particular metal or alloy. Part 6 deals with imperfections in crystals, *i.e.* "mosaic structure," "lineage structure" &c. J. M. ROBERTSON.

IMPORT DUTIES ACT. "*Report on the Import Duties Act Inquiry* (1933). Pt. II. *The Iron and Steel Trades, The Engineering and Vehicles Trades, The Non-Ferrous Metals Trades, The Timber, Paper, Clay, and Building Materials Trades and a General Summary Statement.*" Presented to Parliament in pursuance of the Import Duties Act, 1932. 8vo, pp. xii + 262. London, 1936: H.M. Stationery Office. (Price 4s.)

When the British Government, by the Import Duties Act of 1932, imposed a 10% *ad valorem* Customs duty on all goods (with certain exceptions) imported into the United Kingdom, it made provision for the Board of Trade to review the effects of the duties on industry by the collection of statistical returns. In accordance with this provision an Inquiry into production in the year 1933 was undertaken by the Board in a selected number of industries, and the results have now been published.

Part I. of the Report on that Inquiry has already been issued, and dealt with the following groups of trades: Textiles, Leather and Clothing, Food, Chemical, &c., and certain miscellaneous trades (including Rubber, Fancy Articles, Linoleum, Games and Toys, Sports Requisites, &c.).

The present volume constitutes Part II., which completes the survey, and deals with the Iron and Steel Trades, Engineering and Vehicles Trades, Non-Ferrous Metals Trades and the Paper, Timber, Clay, and Building Materials Trades.

The particulars given include, for each trade, a detailed statement of the quantities (where available) and selling values of the principal

products produced, the average values per unit of most of those goods, and corresponding average values of exports and imports. A comparison of home production with exports and retained imports is also made, showing, in the majority of cases, the share of the home market held by British goods. In each case, the figures given in respect of the year 1933 (the first full year of operation of the Import Duties Act, 1932) are compared with those of 1930 (before the duties were imposed). Estimates are made for each trade of the volume of production in these two years. Finally, particulars are also given of the number of workers employed in the various industries, distinguishing between operative staff and clerical and administrative staff, and giving separate particulars of males and females and of employees over 18 years and under 18 years of age, respectively. For certain trades, information is also given, for the year 1933 only, of the quantity and cost of the principal materials purchased and used.

IRON AND STEEL INSTITUTE. "*Carnegie Scholarship Memoirs*," vol. XXIV. Edited by K. Headlam-Morley. 8vo, pp. viii + 169. London, 1935: The Institute. (Price 16s.)

The Memoirs contain the results of original research work in the metallurgy of iron and steel, carried out by research workers with the aid of grants made by the Iron and Steel Institute from the Andrew Carnegie Research Fund. The present volume contains the following: The Load-Deflection Fatigue Test. A Critical Investigation of Its Application to Steels, by J. W. Cuthbertson; The Ternary System FeO–MnO–SiO_2, by W. R. Maddocks; Effect of Composition on the Corrosion Probability of Iron and Steel, by R. B. Mears; Notched-Bar Toughness of Fusion Welds at Low and High Temperatures, by W. Kleinefenn; The Desulphurisation of Pig Iron and the General Laws Governing the Desulphurisation of Iron, by H. Wentrup.

"*Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung zu Düsseldorf*." Herausgegeben von Friedrich Körber. Band XVII. La. 8vo, pp. 274. Illustrated. Düsseldorf, 1935: Verlag Stahleisen, m.b.H. (Price 27 marks.)

This volume of the "Mitteilungen" contains 23 important communications recording the results of recent investigations carried out in the Research Laboratories of the Kaiser-Wilhelm-Institut für Eisenforschung, under the Directorship of Dr. Friedrich Körber. The investigations reported cover a wide range of subjects of special interest to metallurgists and those engaged in the manufacture of iron and steel. Abstracts of the Reports are to be found in Section II. of the Journal of the Iron and Steel Institute. The present volume contains the following reports: The Valuation of Iron Ores, by W. Luyken; Fatigue Strength and Damping Capacity of Unalloyed Steels in Relation to the Chemical Composition and Heat Treatment, by M. Hempel and C. H. Plock; Focusing Chamber for the X-Ray Reflection Method, by F. Wever and A. Rose; The Action of Carbon as a Reducing Agent in Steelmaking Reactions with Acid Slags, by F. Körber and W. Oelsen; The Influence of the Roll Diameter in the Cold-Rolling of Spring Steel, by W. Lueg and A. Pomp; The Shape of the Stress-Elongation Curves of Steel in the Blue-Heat Temperature Range, by W. Enders and W. Lueg; The Changes with Time of the Mechanical Properties of Newly-Rolled Rails, Particularly of Basic

Bessemer Steel, by F. Körber and J. Mehovar; Influence of the Die, the Lubricant and the Rate of Drawing on the Power Consumption in the Drawing of Fine Steel Wire, particularly on Multiple Drawing Machines, by A. Pomp and H. Heckel; the Equilibria between Iron and Nickel and their Silica-Saturated Silicates, by P. Bardenheuer and E. Brauns; The Course of the Metallurgical Reactions in the Basic Open-Hearth Process, by P. Bardenheuer and G. Thanheiser; The Mechanism of the α–γ Transformation in Iron, by G. Wassermann; X-Ray Investigation of Stress Distribution and Overstraining in Mild Steel, by H. Möller and J. Barbers; Quenching Stresses, by G. Wassermann; The Quenching Power of Various Liquid Quenching Media, by K. G. Speith and H. Lange; The Application of Potentiometric Volumetric Analysis in Ironworks Laboratories. VII.—The Estimation of Cobalt and Manganese by Means of Potassium Ferricyanide, by P. Dickens and G. Maasen; The Recrystallisation of Electrolytic Iron, by G. Wassermann; A New Vacuum Furnace and its Use in the Estimation of Oxygen in Steel, by G. Thanheiser and E. Brauns; Experience with the "Pasopos" Roll Pressure Indicator, by W. Lueg and A. Pomp; Influence of the Material for Rolling, the Rolling Speed, the Strip Width, and Previous Cold Deformation on the Cold-Rolling of Strip, by W. Lueg and A. Pomp; The Reaction of Chromium with Acid Slag, by F. Körber and W. Oelsen; The Effect of Cold-Working and Ageing on the Behaviour of Steel under Alternating Stress, by F. Körber and M. Hempel; Influence of the Speed of Running-through in the Lead Patenting of Steel Wire on the Properties of the Drawn Wire, by A. Pomp and H. Ruppik.

SOCIETY OF CHEMICAL INDUSTRY. "*Reports of the Progress of Applied Chemistry*," vol. XX. 1935. 8vo, pp. 814. London: The Society. (Price 10s.)

This volume reports all the important developments in the field of chemical industry and science which have taken place during the year 1935. The section dealing with the progress in the metallurgy of iron and steel is compiled by Professor C. O. Bannister. This covers 28 pages, and deals with recent investigations in blast-furnace practice, steel manufacture, foundry practice, properties and heat treatment of steel, and corrosion. The contents of the volume are as follows: General, Plant, and Machinery, by H. W. Richards and J. N. Vowler; Fuel, by L. E. Winterbottom and A. H. Raine; Gas, Carbonisation, Tar, and Tar Products, by H. Hollings and W. A. Voss; Mineral Oils, by W. W. Goulston; Colouring Matters and Dyes, by E. H. Rodd and others; Textiles, Fibres, and Cellulose, by J. B. Speakman and Miss E. Stott; Pulp and Paper, by H. A. Harrison; Bleaching, Dyeing, Printing, and Finishing, by H. A. Turner and W. F. A. Ermen; Acids, Alkalis, Salts, &c., by W. A. Damon; Glass, by D. Robertson; Refractories, Ceramics, and Cements, by J. H. Chesters and W. J. Rees; Iron and Steel, by C. O. Bannister; Non-Ferrous Metals, by A. R. Powell; Electro-Chemical and Electro-Metallurgical Industries, by J. W. Cuthbertson; Oils, Fats, and Waxes, by T. P. Hilditch; Paints, Pigments, Varnishes, and Resins, by Members of the Oil and Colour Chemists' Association; Rubber, by W. J. S. Naunton and C. F. Flint; Leather and Glue, by D. Burton; Soils and Fertilisers, by E. M. Crowther; Sugars, by L. Eynon and J. H. Lane; The Fermentation Industries, by R. H. Hopkins and F. W. Norris; Foods, by H. E. Cox; Fine Chemicals and Medicinal Substances, by E. Stedman; Photographic Materials and Processes, by H. V. Horton; Sanitation and Water Purification, by C. Jepson.

STICHTING VOOR MATERIAALONDERZOEK: MEDEDELING No. 10. CENTRALE CORROSIE COMMISSIE. "*Tweede Verslag van Corrosie Commissie II. voor de Bestudering van Buisaantasting door Bodeminoloeden.*" Onderwerp: Aantasting van Buizen. Juli, 1935. (Second Report of the Dutch Corrosion Committee II. for the Study of the Corrosive Effect of Soils on Pipes. Subject: Action of Soil on Iron Pipes). 8vo, pp. 156. 's-Gravenhage, 1935.

In 1931 the Dutch Research Institute for Testing Materials (Stichting voor Materiaalonderzoek) instituted a Corrosion Committee; the present volume is the Second Report of a Sub-Committee appointed to study the corrosion of pipe-lines in soil. The Sub-Committee have decided not to undertake field tests of the type conducted in America, but are investigating the problem by the systematic examination of existing pipe-lines and by laboratory researches. As regards the former they report on 56 examinations of lines in service. They conclude that several of the conclusions reached by American workers are inapplicable to Dutch soils, which they classify as aerobic, anaerobic, and alternately aerobic and anaerobic. In general, severe corrosion is improbable under aerobic conditions, *i.e.* when oxygen has free access to the soil, but may occur under certain conditions in anaerobic and intermittently anaerobic soils. In the latter cases the progress of corrosion is facilitated by the power of certain bacteria to reduce the sulphates in the soil, the oxygen thus derived being available for removing the hydrogen formed in the corrosion process. The Report contains a contribution by Dr. C. A. H. von Wolzogen Kühr in which the connection between the sulphate reduction process with the corrosion process is elucidated in detail.

As a practical step, the Committee favour at the present stage the laying of pipes in sand trenches, should corrosion be feared. It would seem desirable that the sand should contain a certain amount of calcium carbonate and be as free as possible from organic matter. The whole Report, of which an English translation is available in the library of the Iron and Steel Institute, should be of considerable interest to all concerned with the construction and maintenance of buried pipelines.

J. C. HUDSON.

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